Analysis of Non-Tactical Vehicle Utilization at Fort Carson

Final Report

30 March 2012

Contract Number: W56HZV-09-D-0154-0002

Prepared By:

Select Engineering Services (SES)
1544 Woodland Park Dr. Ste. 310
Layton, UT 84041-5698

and

Automotive Insight, LLC
555 S. Old Woodward #1001
Birmingham, MI 48009

Contents

INDEX OF TABLES

INDEX OF FIGURES

Acronyms

2-D	Two Dimensional
ACC	Acceleration
CONUS	Continental United States
DOD	Department of Defense
EV	Electric Vehicle
FAST	Federal Automotive Statistical Tool
GMT	Greenwich Mean Time
GPS	Global Positioning System
HEV	Hybrid Electric Vehicle
kW	Kilowatt
LB	Pound
MPH	Miles Per Hour
NTV	Non-tactical Vehicle
OBD	On-Board Diagnostics
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PID	Parameter Identification (Code)
SAE	Society of Automotive Engineers
TARDEC	Tank Automotive Research, Development and Engineering Center
VIN	Vehicle Identification Number
VSS	Vehicle Speed Signal (Velocity)
VSS^2	Vehicle Velocity Square

Summary

The Army's Tank Automotive Research, Development and Engineering Center (TARDEC) commissioned this study in support of Department of Defense (DOD) vehicle electrification initiatives. The project goals were to evaluate the duty cycle profiles of non-tactical vehicles (NTVs) at Fort Carson in order to assess electrification potential. Vehicle mileage logs exist for the NTV fleet, allowing assessment of periodic usage. However, it is recognized that total mileage accumulated over finite periods of time is not a useful parameter by itself for identifying electrification candidates because it may derive from a mix of very long and very short trips that can make recharging problematic.

One key aspect of vehicle usage is the distance the vehicle travels before returning to its home location (the "barn"). If a vehicle travels distances during a day that exceed what a battery charge might support, it is useful to ascertain whether there are long stopover periods at a location where recharging could be feasible. Therefore, granular information on vehicle location and driving profile is desirable to support electrification plans. The key aspect when compiling such information is the ability to extract trends from this granular information for comparing driving profile characteristics of different vehicles in a quantitative way.

The study scope was limited to acquiring vehicle location data as a function of time using non-intrusive Global Positioning System (GPS) data loggers and extracting information on usage time, distance, vehicle speed and geographic location in terms of quantitative parameters (or metrics) to compare vehicle driving profiles. A standardized Summary Report has been developed that shows key utilization profile metrics for each vehicle monitored. Daily usage statistics for mileage, time, number of trips and speed profile are presented in graphical form to provide a method of assessing trends and conditions to identify vehicle electrification candidates.

Other utilization metrics derived from statistical analysis are addressed in the report. A metric based on the number and severity of deceleration events was also developed which may provide insight for projecting energy recovery potential in an electrified vehicle. Daily Geo Maps showing trip-by-trip tracks for three representative vehicles are also provided as a way to illustrate the typical displacement of a vehicle from its barn in a single day.

The analysis focused on identifying trends among vehicle types and functions by comparing the duty cycle features shown in the Summary Reports. The variability of daily mileage, geographical area of operation and speed profiles are relevant parameters for assessing electrification candidates. On the basis of these parameters, the work trucks deployed at Fort Carson appear to be better electric vehicle candidates than the buses and pool vehicles that drive at higher speeds and travel longer distances during a single day. Trucks assigned to Maintenance and Engineering activities also spend most of their time on or near the base and appear to be good electrification candidates.

1.0 Introduction

The Department of Defense (DOD) owns/operates nearly 200,000 non-tactical vehicles (NTVs) worldwide. Some basic data regarding DOD fleet characteristics are provided in Table 1.

Table 1: Basic fleet characteristics for DOD, based on 2009 Federal Automotive Statistical Tool (FAST) reporting data

	Sedans & Station Wagons	Passenger Vans	Sport Utility Vehicles	Light-Duty Trucks	Medium-Duty Trucks	Heavy-Duty Trucks	Buses	Total/ Average
# Vehicles	38,999	31,757	15,197	41,825	43,535	16,810	5,532	193,655
Avg. Annual Mileage	13,524	8,154	7,858	7,402	6,419	3,773	8,479	8,289
Avg. Daily Mileage (250 use days/yr)	54	33	31	30	26	15	34	33

The DOD is pursuing the replacement of NTVs with more efficient models, alternative fuel vehicles, and hybrid electric vehicles to decrease petroleum demand. DOD is also considering the merits of a large-scale integration of plug-in electric vehicles (PEVs) into its non-tactical ground fleet on a number of military installations in the Continental United States (CONUS). This will support efficiency improvement goals as well as DOD sustainable power initiatives involving microgrids and vehicles capable of two-way power flow to the grid.

The average annual usage for DOD passenger NTVs ranges from 7,858 miles for SUVs to 13,524 miles for sedans. Cargo and work trucks receive lower usage, ranging from 3,773 to 7,402 miles per year, while buses average 8,479 miles per year. Assuming daily usage on work days, this works out to an average usage of 31 – 54 miles per day for passenger vehicles and 15 – 30 miles per day for trucks. While this suggests there is broad potential for electrification of vehicles on CONUS bases, it is important to understand where specific vehicles may travel much higher distances on certain days, or make many trips before returning to a potential recharging location.

The best way to fully understand the operating patterns and duty cycles for NTVs running on bases is to utilize GPS data loggers to monitor vehicle usage and then analyze the data. The resulting duty cycles can lead to identification of the optimal candidates for replacement with hybrid electric, plug-in hybrid, or full electric vehicles.

2.0 Data Collection Methodology

The analysis of driving profiles to project a vehicle's suitability for electrification involves measuring parameters that quantify attributes of the vehicle's duty cycle that affect energy consumption. Accepted examples of such parameters are Mileage, Average Vehicle Speed and Fuel Consumption. Although these parameters can be measured with on-board vehicle data recorders, they are often too general for giving useful insight into the actual duty cycle characteristics and for assessing which vehicles in a fleet are better candidates for electrification. Complex vehicle simulations have been developed for many vehicles in real-world driving conditions that are quite successful in calculating realistic energy savings gained through electrification. However, since the simulations are computational-intensive and require detailed knowledge of the powertrain and drivetrain characteristics and road conditions, they are not widely available to a broad audience.

Thus, for preliminary screening of fleet vehicles that may be candidates for electrification, it can be helpful to identify parameters that can be calculated from data acquired with low investment cost and by means of low complexity algorithms which are nevertheless useful for making quantitative comparisons of driving characteristics that influence "energy consumption." GPS data can be acquired with very low cost devices that are readily installed in the vehicle. Mileage information, utilization time and vehicle speed profiles can be derived from time-dependent GPS data with sufficient accuracy for duty cycle evaluation. Additionally, low resolution acceleration profiles can also be extracted which, combined with vehicle speed data, may provide sufficient information for differentiating between "energy demanding" (many stop & go events) versus "energy miser" (mainly mid-speed cruise) driving behavior.

The project involving monitoring driving profiles of certain non-tactical vehicles at Fort Carson in order to assess what duty cycle information could be derived from GPS data only that is relevant to assessing electrification benefits.

2.1 Vehicle Pool

Five groups of non-tactical vehicles were monitored at Fort Carson, each group during a non-overlapping observation period lasting approximately two weeks. These periods are referred to as Round 1 through Round 5. With two exceptions, each round included different vehicles and an attempt was made to choose vehicles of different types and with a variety of use functions. An opportunistic approach was used in vehicle selection, so the range of vehicles monitored is not statistically representative of the overall non-tactical vehicle fleet assets on the base. The selection of the two-week observation period derived from considerations of vehicle availability, data retrieval issues and hardware limitations. Other studies known to TARDEC supported the use of a two-week period as sufficiently long to derive meaningful

duty cycles. The full list of vehicles monitored with their functions and observation periods is shown in Table 2 below.

Table 2: Vehicles monitored during the project

Rnd	Vehicle Type	Function	Observ. Period	Logger
1	04 Ford F250 Pickup	Engineering	Sep 12-28, 2011	AI-01
1	03 Chevy C2500 4X4 Pickup	Pool	Sep 12-28, 2011	AI-02
1	04 Ford E350 Chassis	Ambulance	Sep 12-28, 2011	AI-03
2	11 Chev. Expr 12-Psgr Van	Pool (Exec Van)	Nov 9-30, 2011	AI-01
2	11 Ford F-250 Box Truck	Work Truck	Nov 9-30, 2011	AI-02
2	10 Dodge Ram 2500	Work Truck	Nov 13-21, 2011	AI-03
3	11 Dodge Ram 1500 (FFV/E	Maint/Supply Activ	Dec 8-22, 2011	AI-01
3	10 Ford Ranger XLT Pickup	Maint/Supply Activ	Dec 8-22, 2011	AI-02
3	03 Ford E-450 25-Psgr Bus	Transport Bus	Dec 8-22, 2011	AI-03
3	11 Dodge Ram (FFV/E85)	DPW Fleet Manage	Dec 5-20, 2011	OBD4
4	11 Ford F-250	Work Truck	Jan 24-Feb 7, 2012	OBD1
4	08 Ford F-150	Work Truck	Jan 24-Feb 7, 2012	AI-01
4	06 Ford F-150	Work Truck	Jan 24-Feb 7, 2012	OBD2
4	06 Dodge Dakota	Work Truck	Jan 24-Feb 7, 2012	OBD3
4	07 Ford LCF Flat Bed	Delivery Flat Bed	Jan 25-Feb 7, 2012	AI-02
4	85 Dodge Ram	Work Truck	Jan 25-Feb 7, 2012	AI-03
4	Ford E-450 25-Psgr Bus	Transport Bus	Jan 26-Feb 7, 2012	OBD4
5	09 Chevy Avalanche	Maintenace	Feb 8-22, 2012	OBD1
5	09 Chevy 4500 Kodiak	Ambulance	Feb 8-22, 2012	AI-01
5	04 Ford E-350	Ambulance	Feb 8-22, 2012	OBD3
5	04 Ford E-350	Ambulance	Feb 8-22, 2012	OBD2

2.2 Data Acquisition

The initial intent for the project was to conduct a low investment study of vehicle usage based on data from low-cost GPS loggers. Three TranSystem 747ProS units were initially purchased and used in all five monitoring rounds. These units are referred to as GPS loggers throughout this report. Evaluation of the Round 1 data indicated that the GPS logger was not able to provide a direct indication of Idle Time, that is, the time the engine is running but the vehicle is not moving. This type of logger could only record vehicle position as a function of time. Even Key Off conditions, potentially very different from true Engine On/Off conditions, could have only been tracked by manually switching the device on and off upon turning the engine on and off. This was deemed unacceptable in this evaluation due to the

desire to not require active participation in equipment operation by drivers of the vehicles being monitored.

Therefore, a different type of logger (the IOSiX OBD-II port device) was purchased for Round 3 to measure Idle Time directly. This unit combines an OBD-II and GPS logger and allows the detection of Engine On/Off periods through the OBD-II port functionality. Three additional IOSiX units, referred to as OBD loggers, were subsequently purchased for Rounds 4 and 5, increasing the number of vehicles monitored in the last two rounds to seven. The GPS loggers were still used because they provided all the other information required for duty cycle analysis. Additionally, as supported by the true Idle Time observations with the OBD loggers, a rough estimation of Idle Time could be derived from the GPS-only data by assuming that the engine was not actually turned off during rest periods of 120 seconds or less.

2.3 Data Sets

Both the GPS and OBD loggers acquired data sets as time series, that is, values of parameters associated with a timestamp. For the GPS logger case (the 747ProS), all the data was saved in a single file. After conversion into engineering units by means of a provided application, the data to be processed consisted of a single two-dimensional (2-D) array, each column corresponding to a parameter such as latitude, longitude, altitude, velocity, and heading. The Greenwich Mean Time (GMT) timestamp was also given as date and time in separate columns. The recording rate, however, was not constant. Because of power and memory size considerations, the logger was programmed to record data every 30 seconds if motion was not detected and to switch to recording every 1 second as soon as the vibration sensor embedded in the unit detected movement. The conversion application also had a graphical interface based on Google Earth to display the overall vehicle track for the whole period. However, no track splitting capabilities were offered with the application, thus, the Geo Maps had to be reconstructed independently.

The OBD loggers produced two files for each Engine-On event, one for GPS information and the other for the programmable vehicle parameters data. The GPS file included latitude, longitude, altitude, velocity and heading with satellite synchronization information to discriminate for bad data. The timestamp was given as GMT date and time in separate fields. The other file included metadata including the date and time the file was created, the vehicle identification number (VIN) and supported diagnostic parameter identification codes (or PIDs), followed by the vehicle parameter values the unit was programmed to collect arranged as a 2-D array, one parameter per column. These data were acquired based on the SAE J1979 Mode $01 diagnostic protocol. Even if the parameters were polled cyclically one after the other, a unique time stamp was given as the relative time from the beginning of the data-stream initiation.

3.0 Data Analysis and Results

3.1 Data Pre-Processing

The raw data for each vehicle was processed into a suitable input for the duty cycle analysis, the key being to reduce the data-series into a single frequency so that meaningful distributions could be calculated. Because the data from the GPS logger were not recorded at a constant rate, the data subset relative to the vehicle motion had to be extracted while retaining the native timestamps.

For the OBD logger data, the separate files had to be merged and time-aligned to a continuous timeline. While the vehicle speed data derived from the GPS module and from the OBD-II module of the IOSiX data logger were in overall agreement, the duty cycle analysis was performed on the latter since the GPS module was often found to be slow in initiating recording. Since it was desired to compare vehicle speed traces with geographical location, it was important to properly time-align the two data sets.

All of the data pre-processing, analysis, and data rendering to generate the graphical displays was done in MATLAB, including generation of the Geo maps since the IOSiX device did not come with a custom tool for exporting the data into Google Earth. Geo maps for the GPS logger data were also generated in MATLAB since no track splitting capabilities were available in the mapping software provided with the TranSystem GPS logger.

3.2 Data Analysis and Display

The analysis focused on deriving information to capture overall and daily assessments of distance, usage time, idle time, speed profiles, and number of trips. The information is collated into a custom developed template (Graphical Summary Report) which is useful for comparing differences in utilization characteristics across vehicles, both qualitatively and quantitatively.

This Summary Report has been formatted to display information using different building blocks with increasing level of granularity. The trip statistics reported in the table at upper left are considered Global Parameters since they capture mileage, time and vehicle-speed features relative to the entire observation period. The bar charts immediately below show similar information calculated on a daily basis. The vehicle speed distribution indicates how often the vehicle is driven at different speeds. The Geo Map shows the track of the vehicle over the entire observation period which complements the speed distribution information by differentiating between residential and highway driving.

The vehicle speed trace for the full two-week observation period is shown at the bottom of the Summary Report. Although the details of the vehicle motion are lost at this compressed scale, it provides a qualitative assessment of how continuously the vehicle was used and during which time periods during the day. This information cannot be derived by either

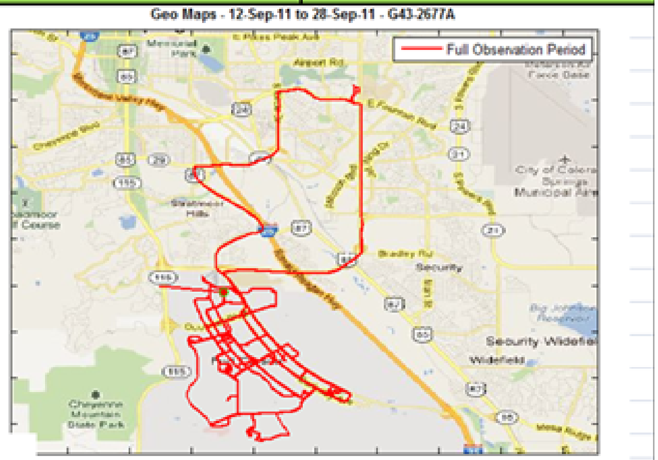
mileage or time alone, or even by combining both. It is also useful to assess whether high speed driving occurs only on occasional days since such insight cannot be gained from the vehicle speed distribution plot. The bar chart showing the Number of Daily Trips provides a quantitative metric that cannot be appreciated in the compressed speed trace, especially when the Number of Trips is large.

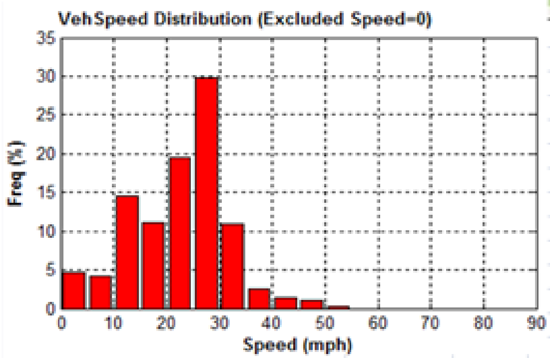
A detailed description of each of the entries and charts in the Graphical Summary Report is provided in Appendix D, along with additional explanation of how certain parameters were calculated and what they mean.

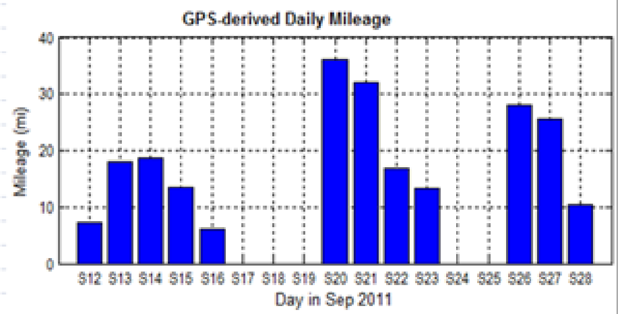
3.3 Individual Vehicle Summary Reports

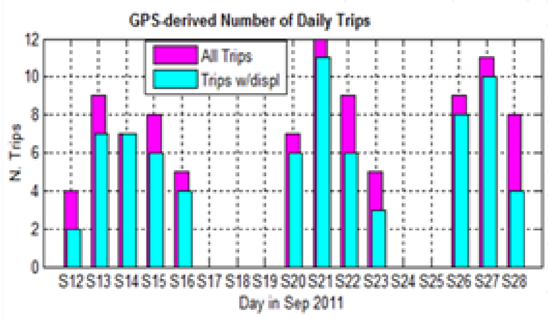
A Graphical Summary Report showing the trip statistics, Geo Map, and usage profile for each of the 24 vehicles monitored during the study is shown on the following pages.

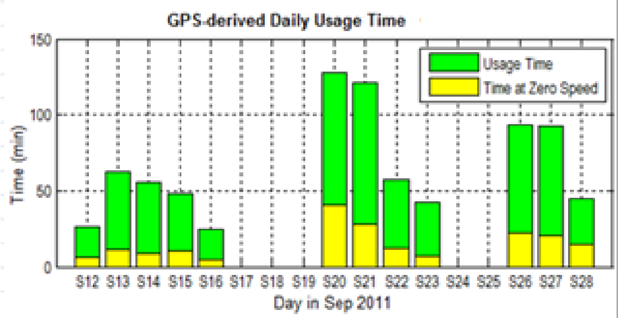
	Obesrvation Period 12-Sep-11 to 28-Sep-11	Engineering- F-250
Total Mileage (mi)	226	
Highest Daily Mileage (mi)	36	
Observation Time (dd)	17	
N. Days of Utilization	12	
Utilization Time(hh:mm)	13:17	
Time at Speed (hh:mm)	10:10	
% Idle Time	23%	
Average Speed (mph)	22.5	
% Time Speed>=40 mph	3%	
N. Estimated Starts	94	
%Accel Time	16%	
% Decel Time	15%	
% Cruise	46%	

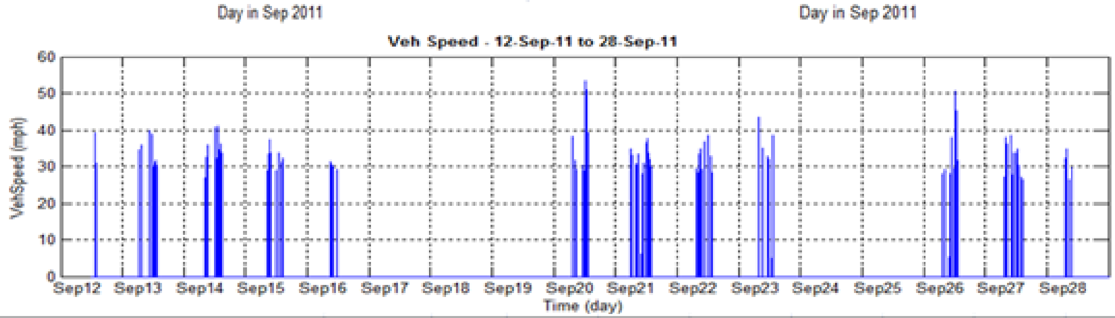






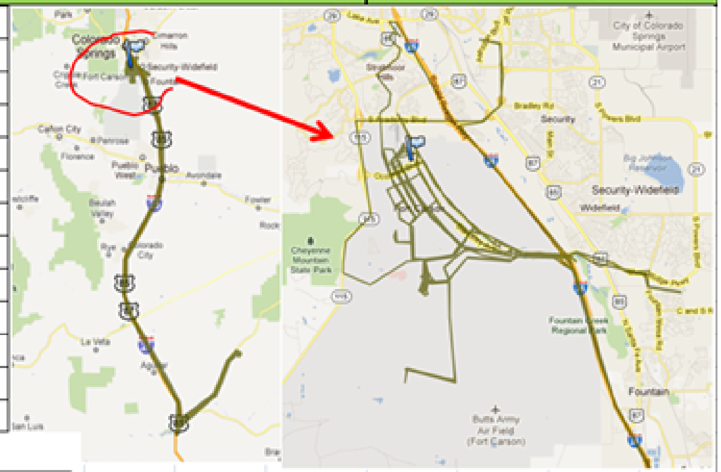


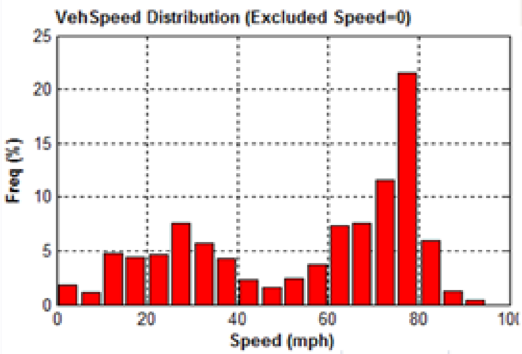


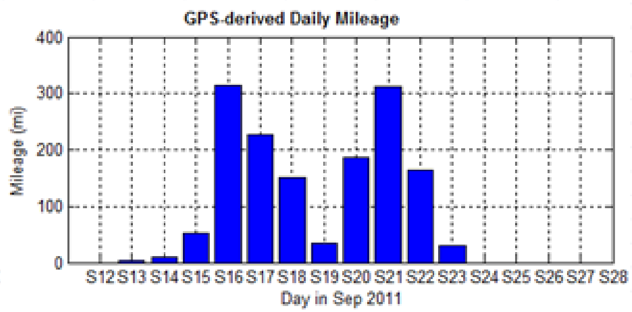


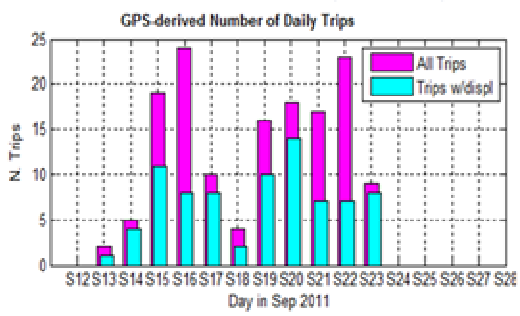
Notes. Round1. GPS Logger, dual data acquisition rate (every 5 sec or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off.

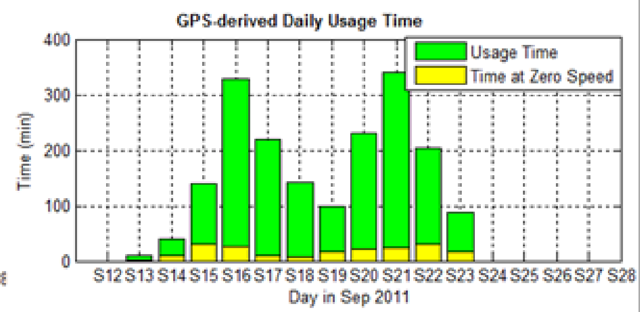
	Obesrvation Period 12-Sep-11 to 28-Sep-11
	Pool Vehicle - Chevy C2500
Total Mileage (mi)	1491
Highest Daily Mileage (mi)	314
Observation Time (dd)	16
N. Days of Utilization	11
Utilization Time(hh:mm)	30:38
Time at Speed (hh:mm)	27:24
% Idle Time	11%
Average Speed (mph)	54.5
% Time Speed>=40 mph	66%
N. Estim. Trips	147
%Accel Time	20%
% Decel Time	19%
% Cruise	50%

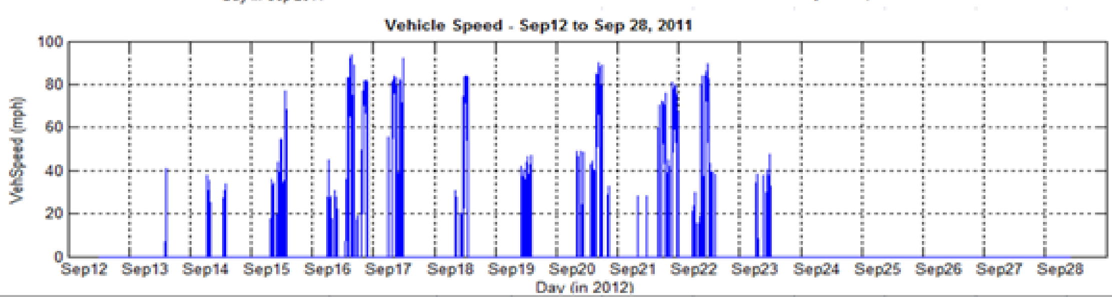






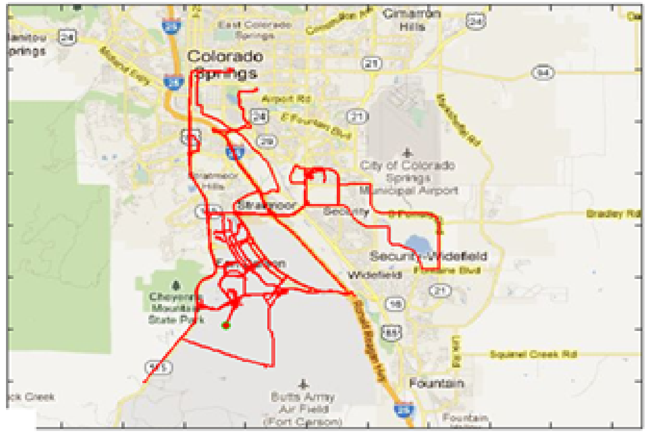


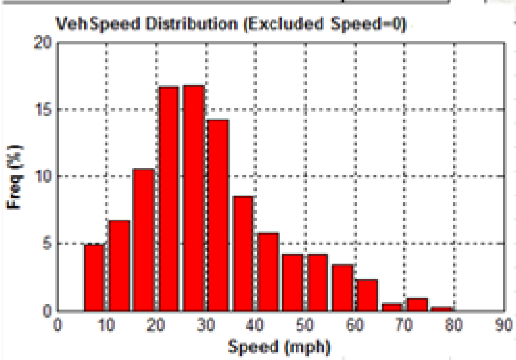


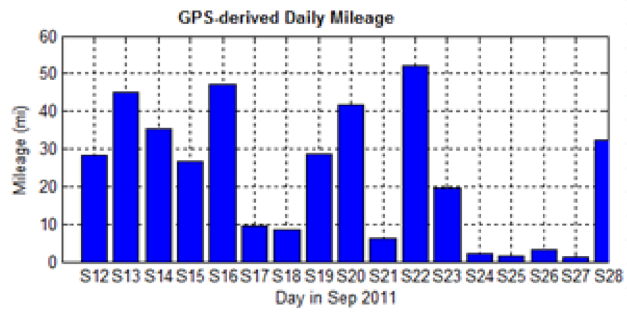


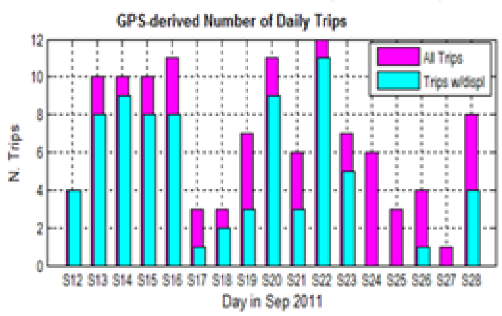
Notes. Round1 GPS Logger, dual data acquisition rate (every 5 sec or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off.

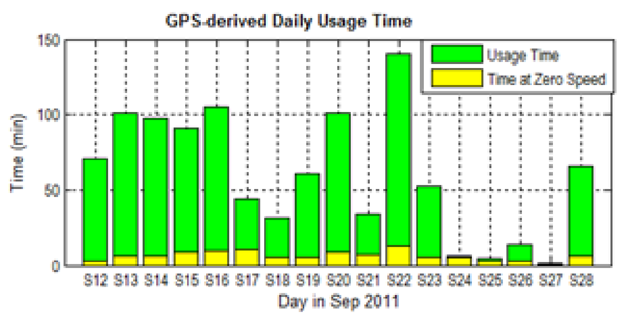
	Observation Period	Ambulance - Ford E-350
Total Mileage (mi)	372	
Highest Daily Mileage (mi)	52	
Observation Time (dd)	17	
N. Days of Utilization	17	
Utilization Time(hh:mm)	17:01	
Time at Speed (hh:mm)	15:15	
% Idle Time	10%	
Average Speed (mph)	30.5	
% Time Speed>=40 mph	22%	
N. Estimated Starts	116	
%Accel Time	20%	
% Decel Time	20%	
% Cruise	50%	

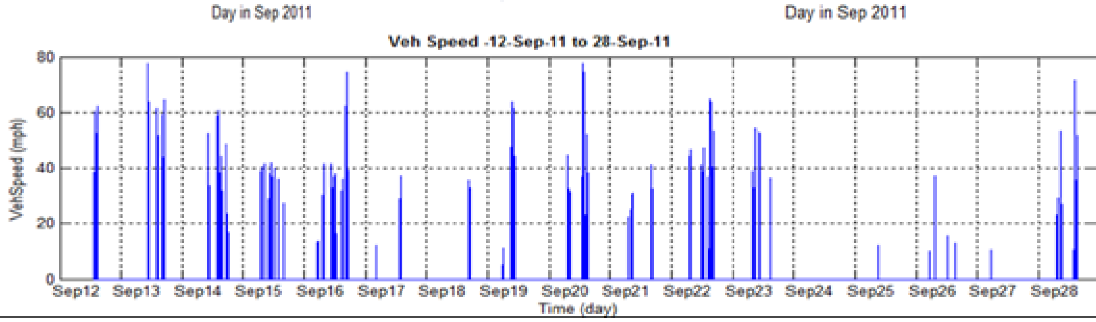








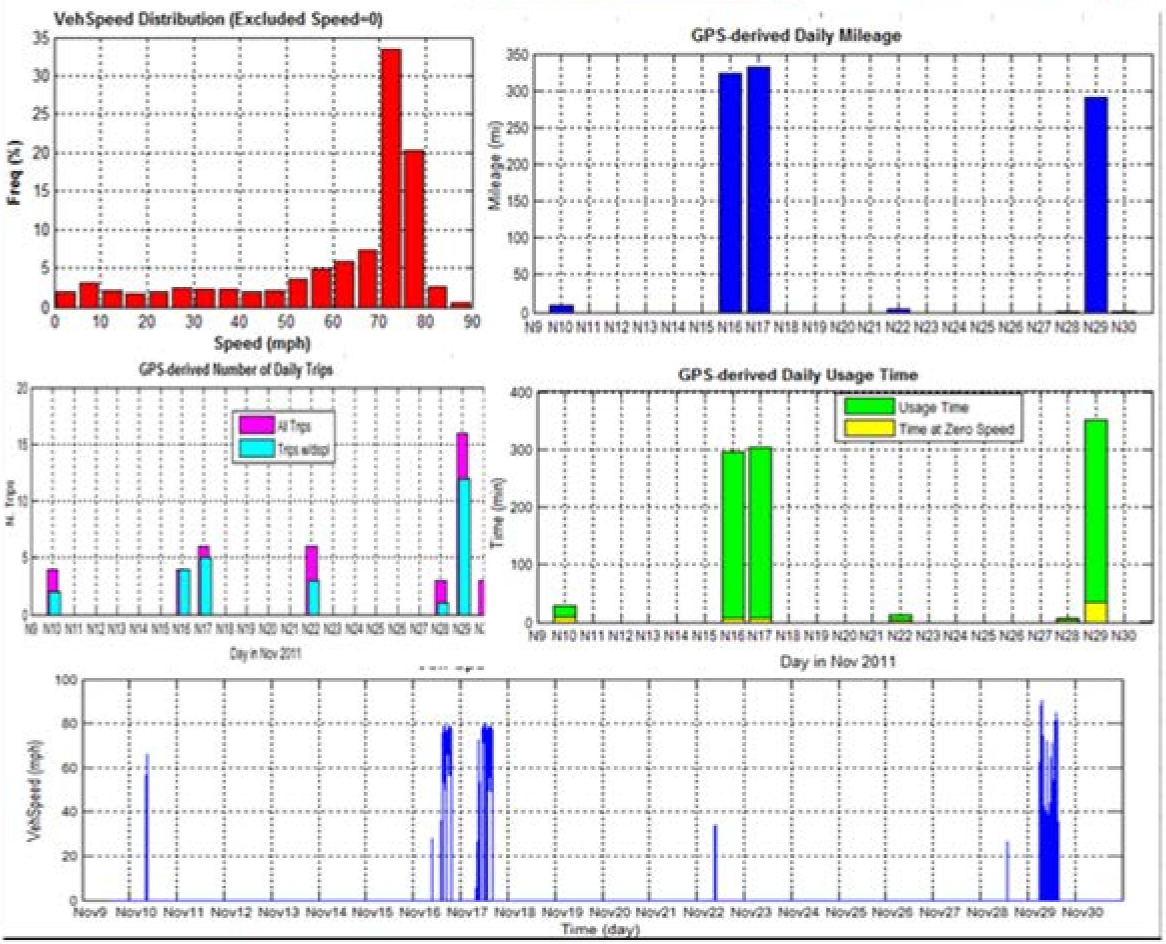




Notes. Round1 GPS Logger, dual data acquisition rate (every 5 sec or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off. GPS noise due to unsteady satellite sync in parking structure and other areas removed with a 5 mph vehicle speed cut-off.

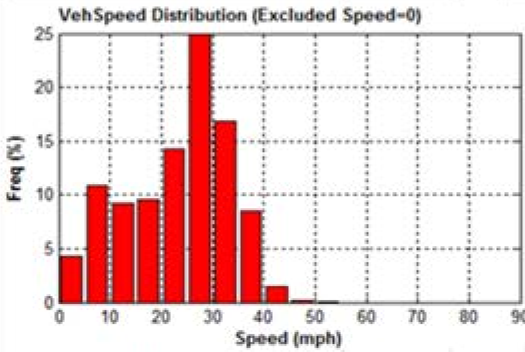
	Observation Period 9-Nov-11 to 30-Nov-11
Total Mileage (mi)	958
Highest Daily Mileage (mi)	32
Observation Time (dd)	22
N. Days of Utilization	7
Utilization Time(hh:mm)	16:41
Time at Speed (hh:mm)	15:41
% Idle Time	6%
Average Speed (mph)	61.3
%Time Speed>=40 mph	82%
N. Estimated Starts	42
%Accel Time	7%
% Decel Time	7%
% Cruise	80%

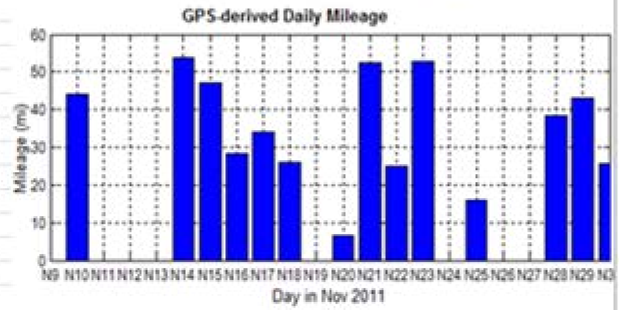
12 Psgr. Van - Chevy Exp

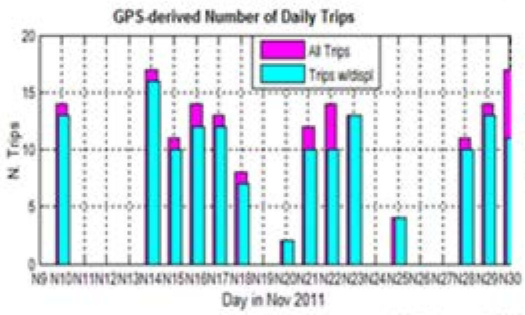


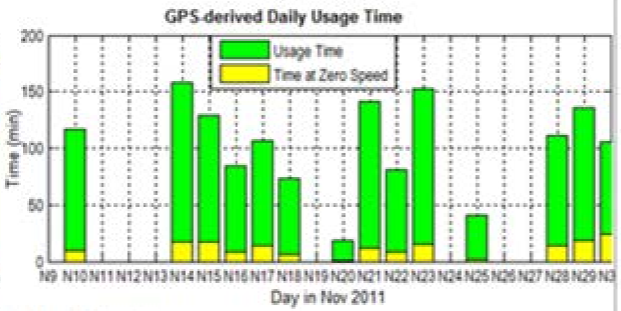
Notes. Round2 GPS Logger, dual data acquisition rate (every 1 sc or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off. The logger was installed late on Nov9.

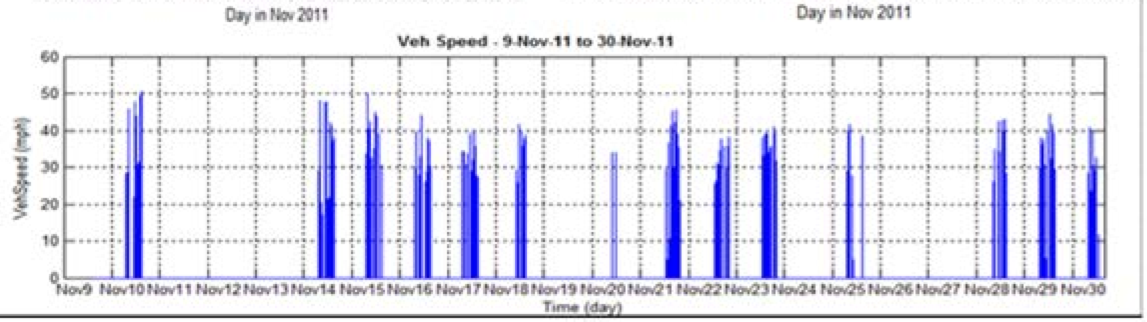
	Observation Period 9-Nov-11 to 30-Nov-11	Work Truck - Ford F-250
Total Mileage (mi)	493	
Highest Daily Mileage (mi)	54	
Observation Time (dd)	22	
N. Days of Utilization	15	
Utilization Time(hh:mm)	24:17	
Time at Speed (hh:mm)	21:28	
% Idle Time	12%	
Average Speed (mph)	23.2	
%Time Speed>=40 mph	2%	
N. Estimated Starts	165	
%Accel Time	17%	
% Decel Time	16%	
% Cruise	55%	





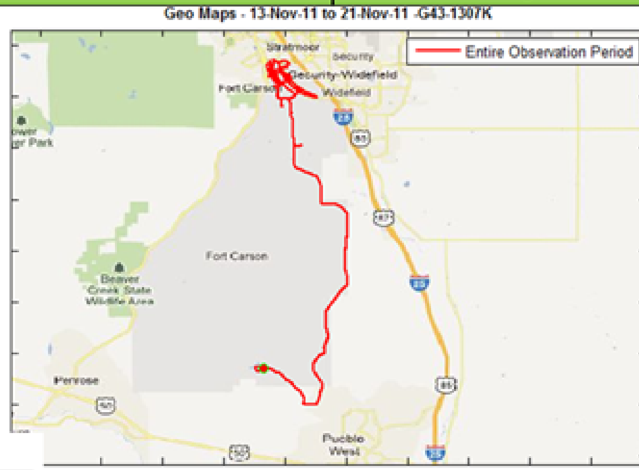


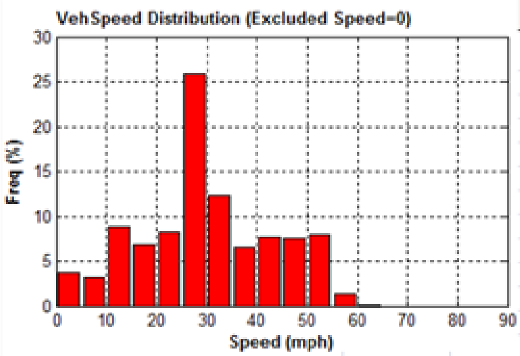


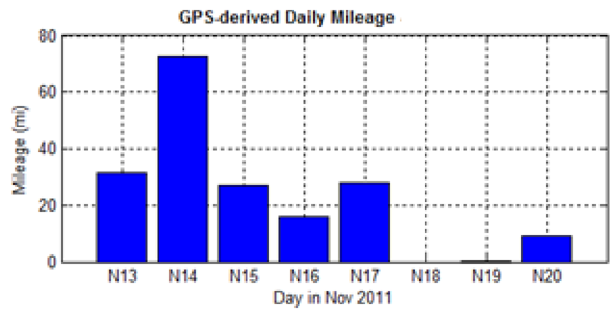


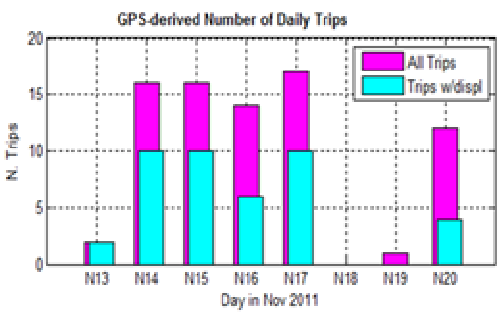
Notes. Round2 GPS Logger, dual data acquisition rate (every 1 sc or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off. The logger was installed late on Nov9.

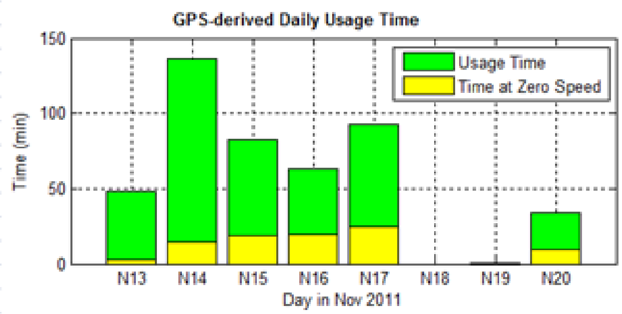
	Observation Period 13-Nov-11 to 21-Nov-11	Work Truck - Dodge Ram Pickup
Total Mileage (mi)	184	
Highest Daily Mileage (mi)	73	
Observation Time (dd)	8	
N. Days of Utilization	7	
Utilization Time(hh:mm)	7:36	
Time at Speed (hh:mm)	6:06	
% Idle Time	20%	
Average Speed (mph)	30	
% Time Speed>=40 mph	25%	
N. Estimated Starts	78	
%Accel Time	15%	
% Decel Time	13%	
% Cruise	42%	

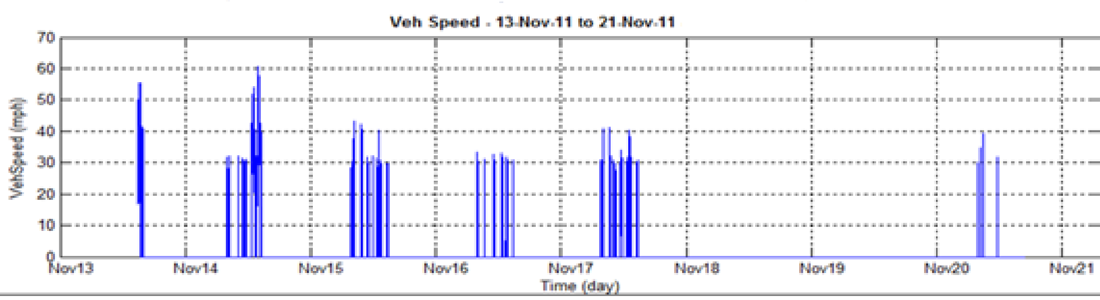






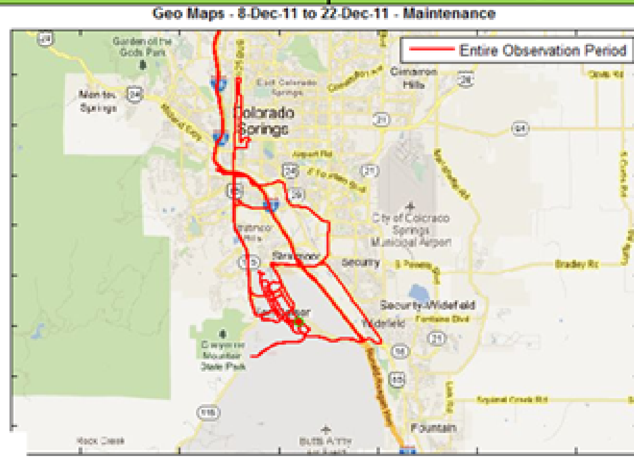


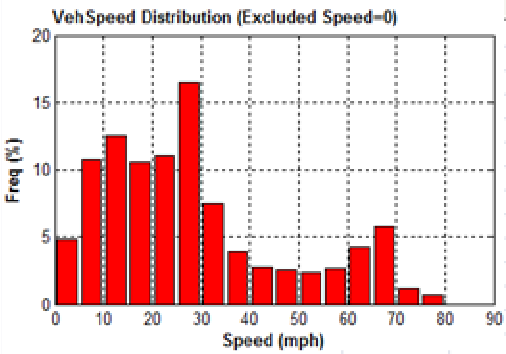


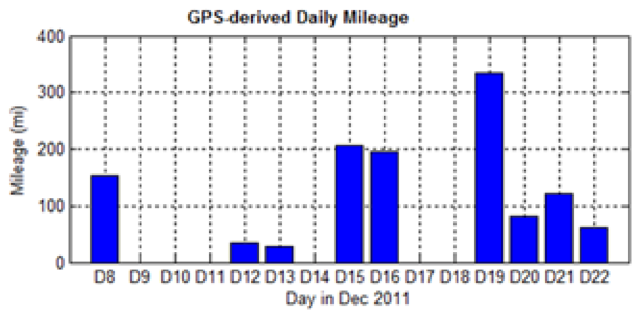


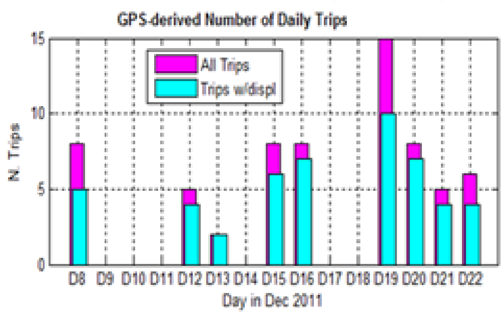
Notes. Round2 GPS Logger, data acquisition rate every 5 sec. Idle estimate with a 120 sec cut-off. The logger was not powered during the monitoring period and its battery discharged after 8 days terminating the data acquisition.

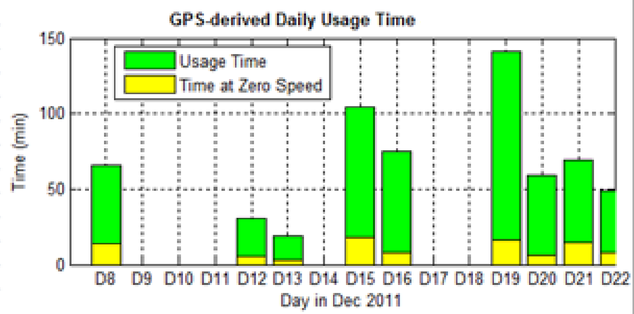
	Observation Period 8-Dec-11 to 22-Dec-11	Maintenance - Dodge Ram 1500
Total Mileage (mi)	244	
Highest Daily Mileage (mi)	67	
Observation Time (dd)	15	
N. Days of Utilization	9	
Utilization Time(hh:mm)	10:14	
Time at Speed (hh:mm)	8:40	
% Idle Time	15%	
Average Speed (mph)	28.5	
% Time Speed>=40 mph	22%	
N. Estimated Starts	65	
%Accel Time	17%	
% Decel Time	17%	
% Cruise	51%	

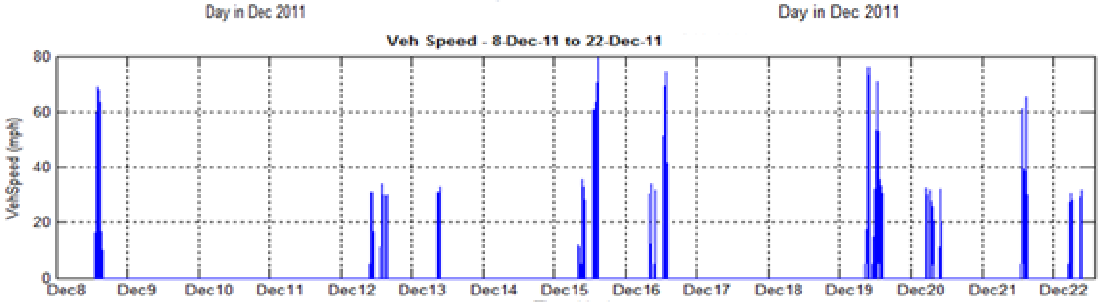






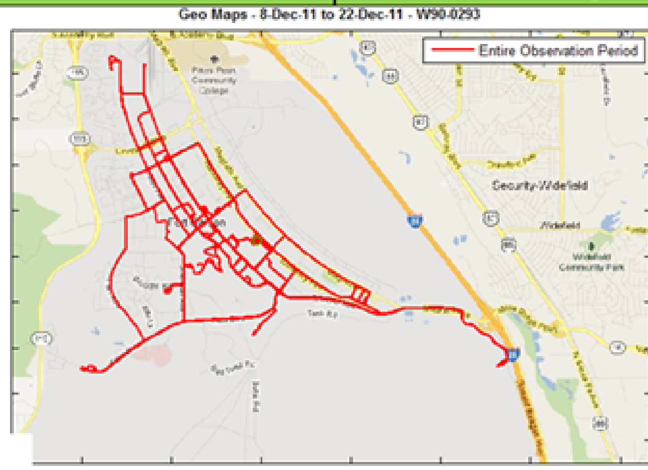


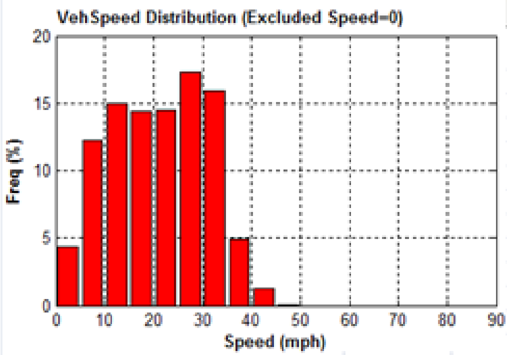


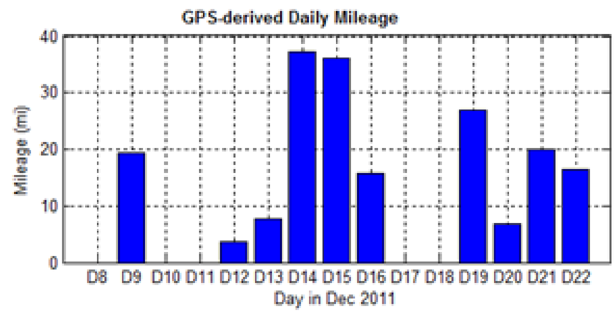


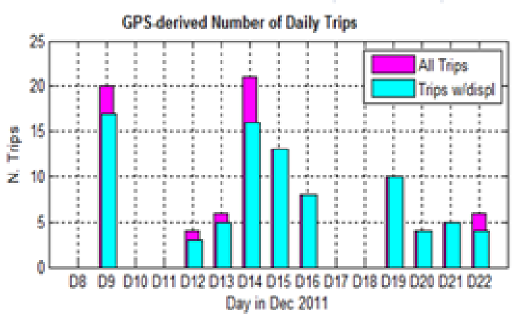
Notes. Round3 GPS Logger, dual data acquisition rate (every 1 sec or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off.

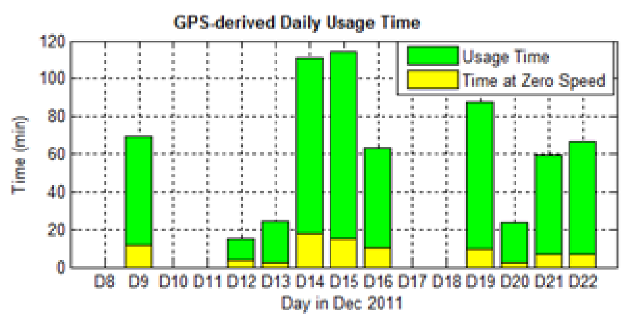
	Observation Period 8-Dec-11 to 22-Dec11	Maintenance - Ford Ranger XTL
Total Mileage (mi)	193	
Highest Daily Mileage (mi)	37	
Observation Time (dd)	15	
N. Days of Utilization	10	
Utilization Time(hh:mm)	10:34	
Time at Speed (hh:mm)	9:06	
% Idle Time	14%	
Average Speed (mph)	21	
%Time Speed>=40 mph	1%	
N. Estimated Starts	97	
%Accel Time	22%	
% Decel Time	18%	
% Cruise	45%	

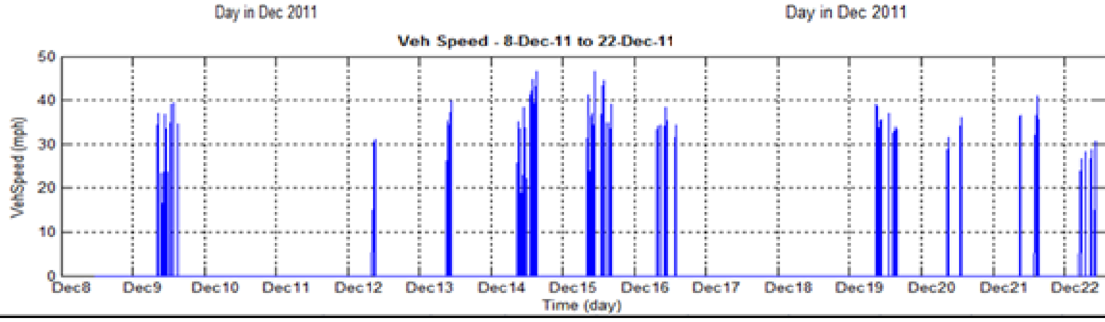








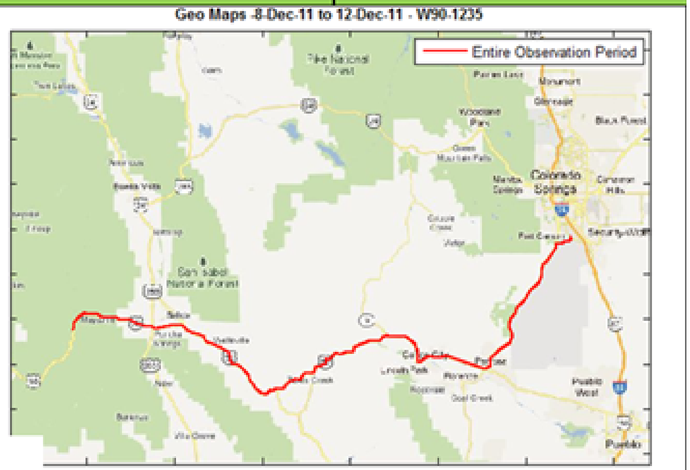


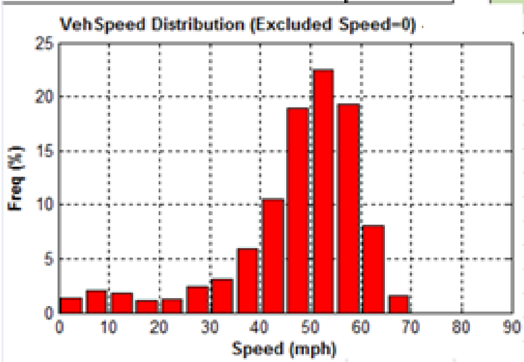


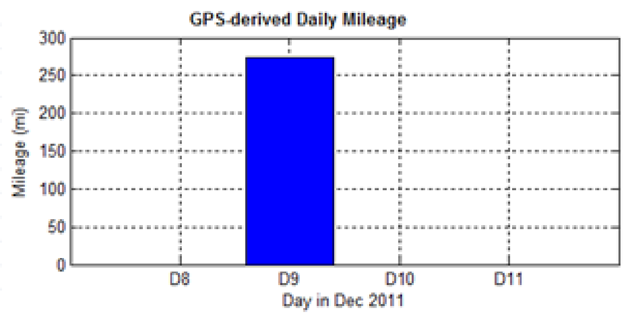
Notes. Round3 GPS Logger, dual data acquisition rate (every 1 sec or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off.

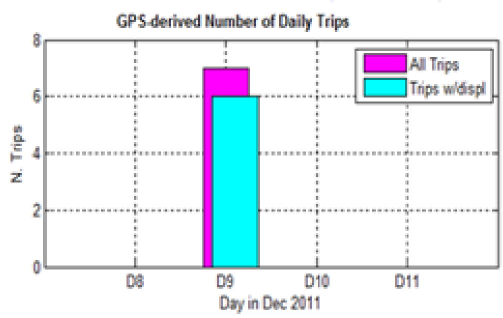
	Observation Period 8-Dec-11 to 22-Dec-11
Total Mileage (mi)	273
Highest Daily Mileage (mi)	273
Observation Time (dd)	4
N. Days of Utilization	1
Utilization Time(hh:mm)	5:52
Time at Speed (hh:mm)	5:46
% Idle Time	2%
Average Speed (mph)	47.3
%Time Speed>=40 mph	81%
N. Estimated Starts	7
%Accel Time	8%
% Decel Time	7%
% Cruise	83%

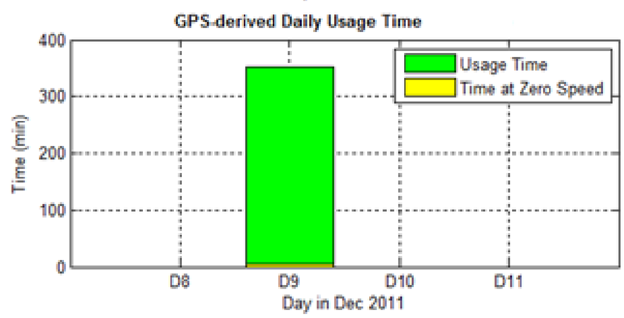
DFMWR Activities - Ford E-450

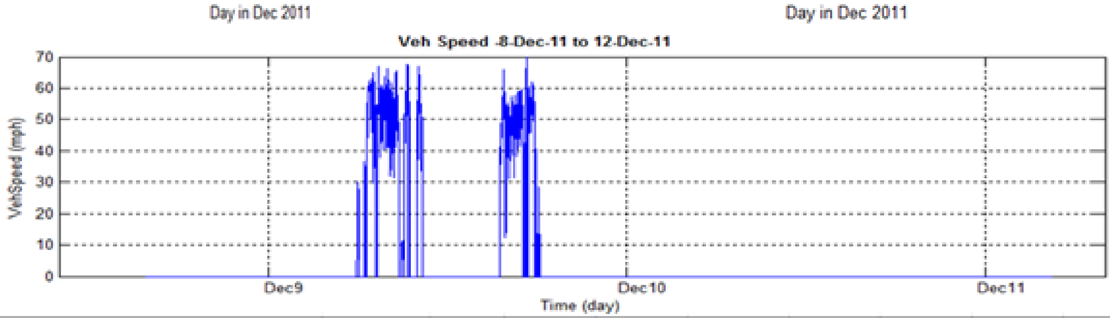






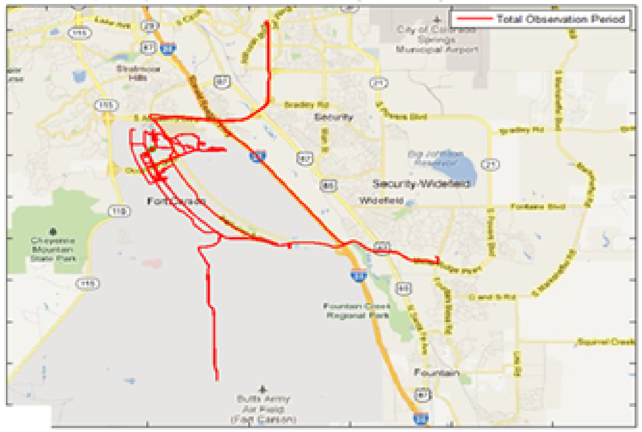


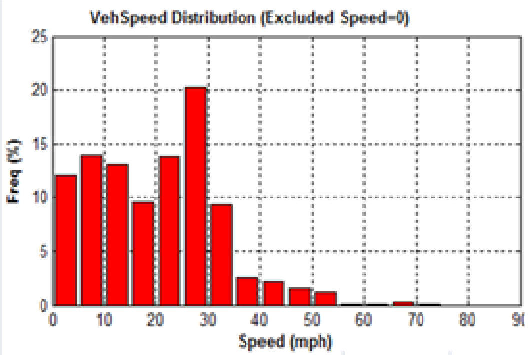


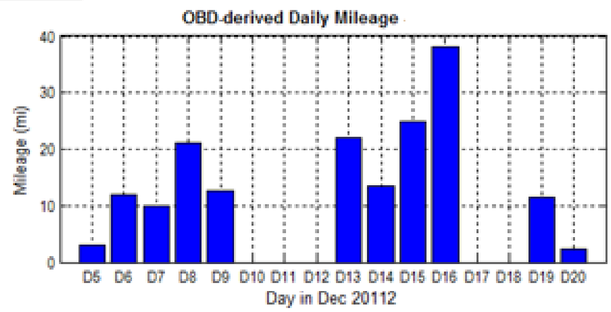


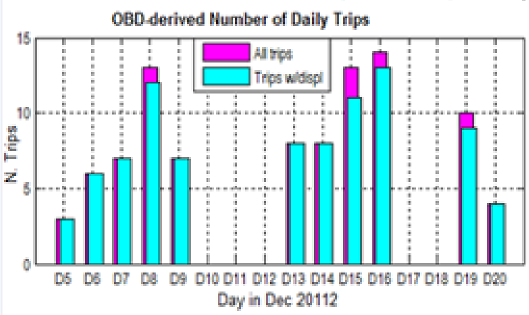
Notes. Round3 GPS Logger, data acquisition rate continuously at every 1 sec. The acquisition halted at Dec11 because the logger memory was full.

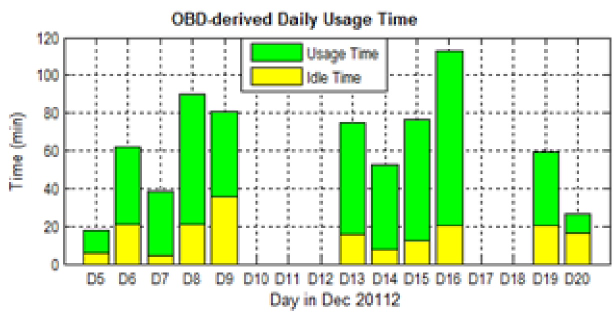
	Observation Period 5-Dec-11 to 20-Dec-11	DPW Fleet Manager- Dodge Ram
Total Mileage (mi)	171	
Highest Daily Mileage (mi)	38	
Observation Time (dd)	16	
N. Days of Utilization	11	
Utilization Time(hh:mm)	11:33	
Time at Speed (hh:mm)	8:34	
% Idle Time	26%	
Average Speed (mph)	19.9	
%Time Speed>=40 mph	5.5%	
N. Total Starts	93	
%Accel Time	18%	
% Decel Time	17%	
% Cruise	39%	

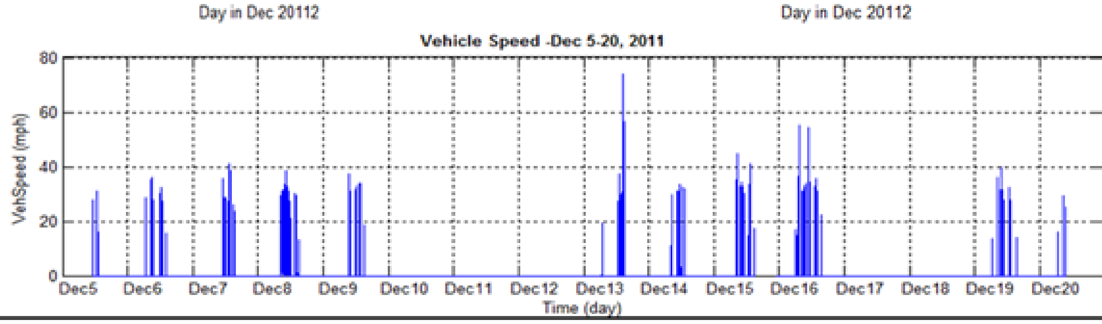










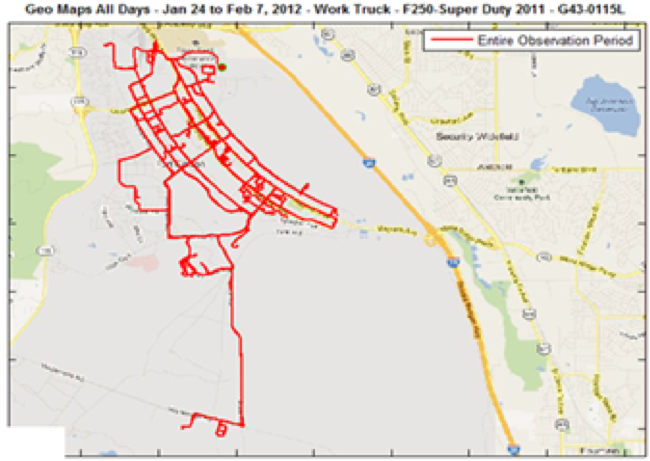


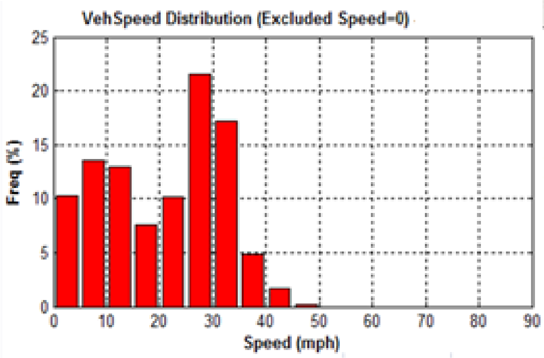
Notes. Round3 OBD Logger

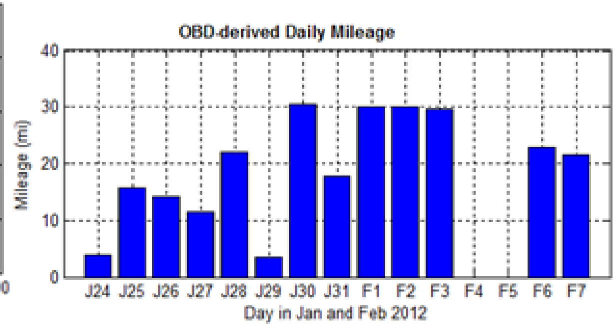
	Observation Period 24-Jan-12 to 7-Feb-12
Total Mileage (mi)	253
Highest Daily Mileage (mi)	30.4
Observation Time (dd)	15
N. Days of Utilization	13
Utilization Time(hh:mm)	18:20
Time at Speed (hh:mm)	12:16
% Idle Time	33%
Average Speed (mph)	20.6
% Time Speed>=40 mph	2%
N. Total Starts	153
%Accel Time	16%
% Decel Time	15%
% Cruise	36%

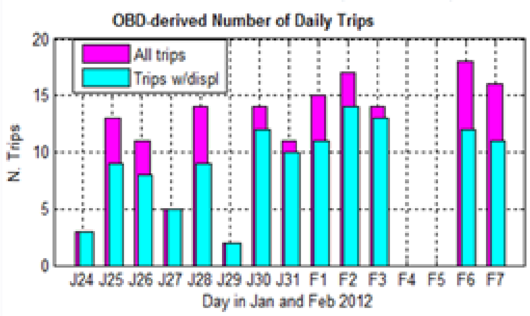
Work Truck - F250 Super Duty

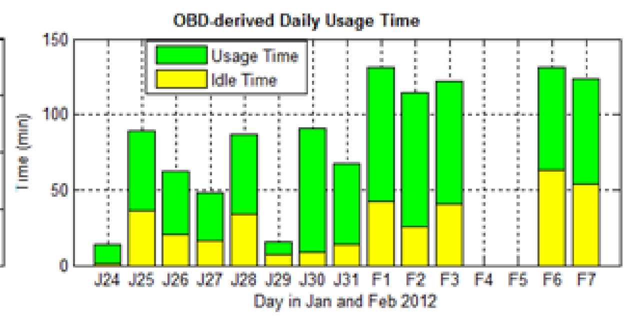
Geo Maps All Days - Jan 24 to Feb 7, 2012 - Work Truck - F250-Super Duty 2011 - G43-0115L

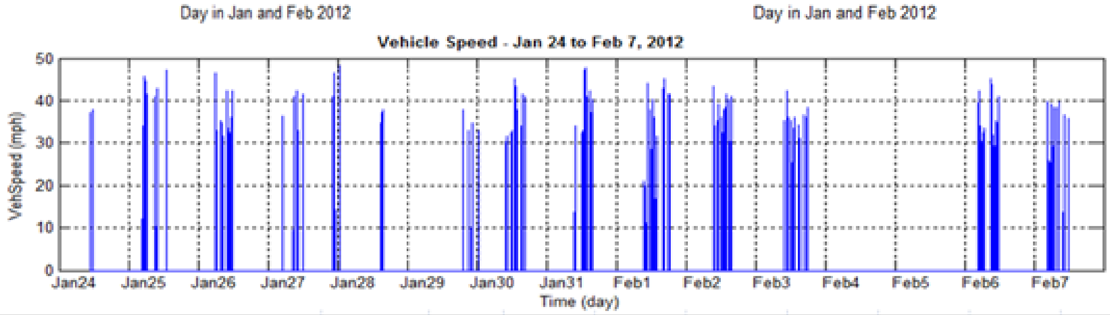






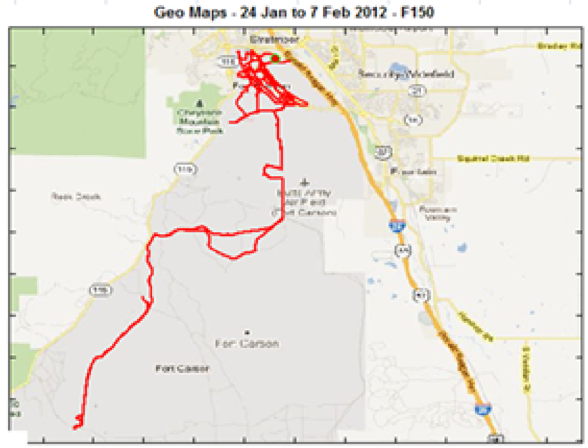


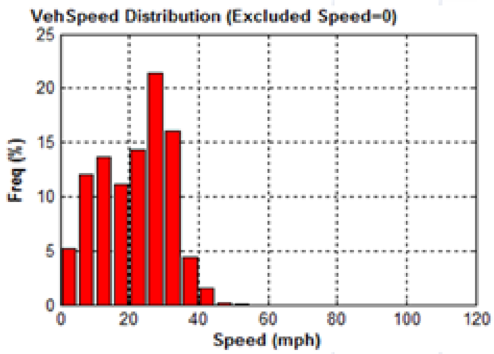


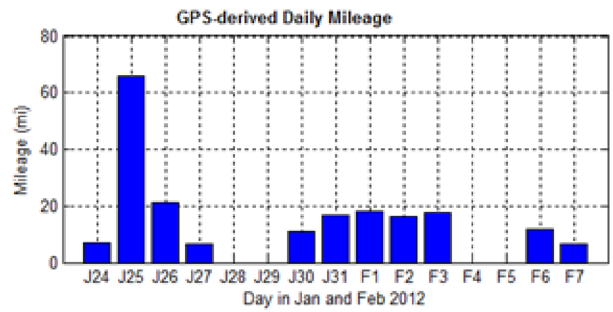


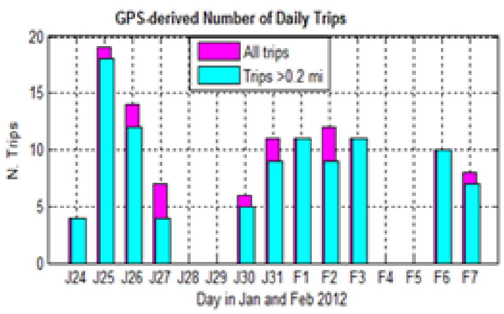
Notes. Round4 OBD logger.

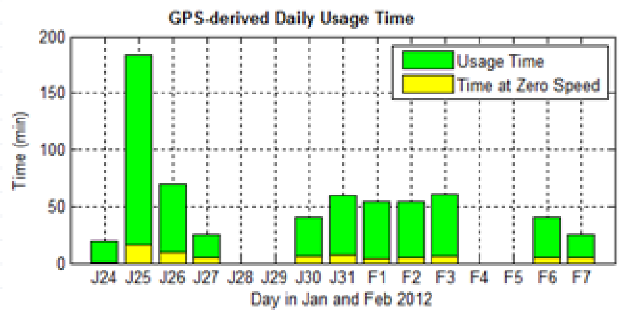
	Observation Period 24-Jan-11 to 7-Feb-12	Work Truck - F150
Total Mileage (mi)	199	
Highest Daily Mileage (mi)	66	
Observation Time (dd)	15	
N. Days of Utilization	11	
Utilization Time(hh:mm)	10:34	
Time at Speed (hh:mm)	9:25	
% Idle Time Estimated	11%	
Average Speed (mph)	21.4	
%Time Speed>=40 mph	2%	
N. Estimated Starts	113	
%Accel Time	20%	
% Decel Time	19%	
% Cruise	50%	

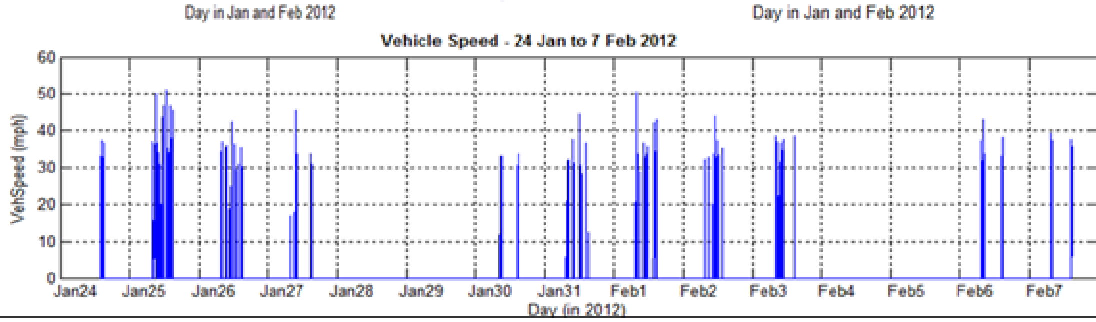






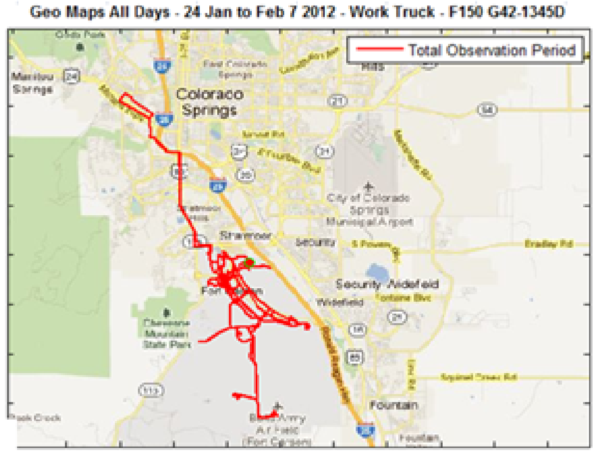


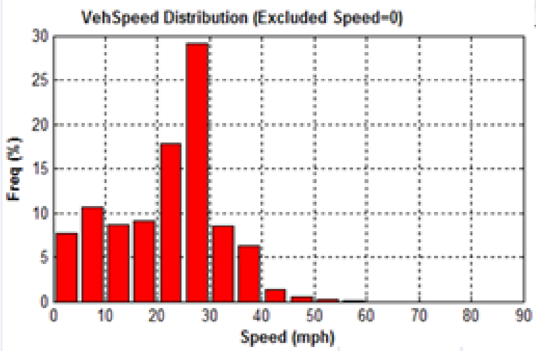


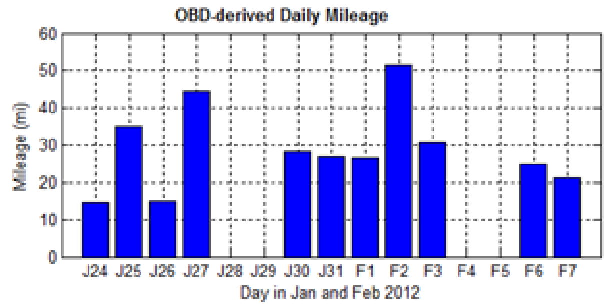


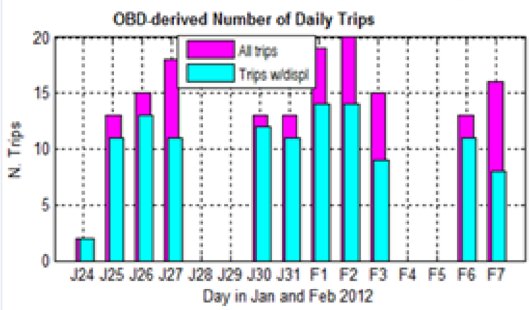
Notes. Round4 GPS Logger, dual data acquisition rate (every1 sec or ecery30 sec depending on motion). Idle estimated with a 120 sec cut-off.

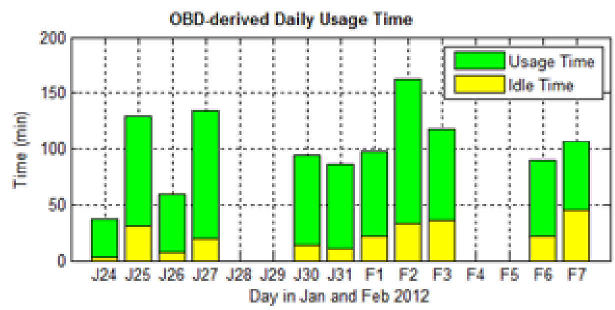
	Observation Period 24-Jan-12 to 7-Feb-12	Work Truck - F 150
Total Mileage (mi)	319	
Highest Daily Mileage (mi)	51.3	
Observation Time (dd)	15	
N. Days of Utilization	11	
Utilization Time(hh:mm)	18:38	
Time at Speed (hh:mm)	14:37	
% Idle Time	22%	
Average Speed (mph)	21.8	
%Time Speed>=40 mph	2%	
N. Total Starts	157	
%Accel Time	15%	
% Decel Time	15%	
% Cruise	48%	

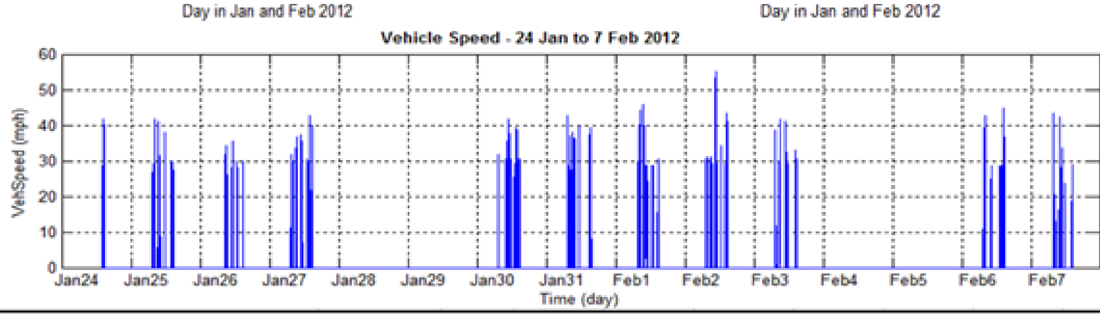








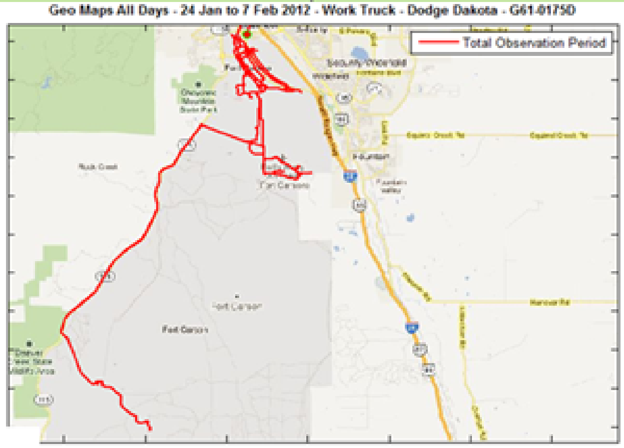


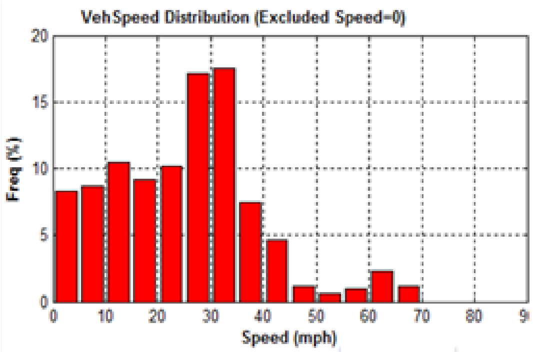


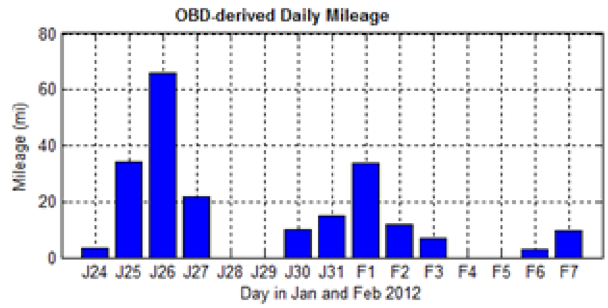
Notes. Round4 OBD logger.

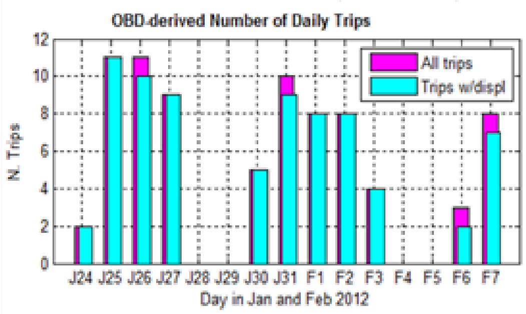
Observation Period 24-Jan-12 to 7-Feb-2012 | **Work Truck - Dodge Dakota**

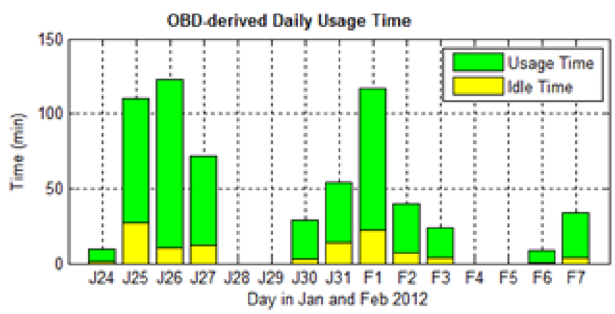
Total Mileage (mi)	215
Highest Daily Mileage (mi)	66
Observation Time (dd)	15
N. Days of Utilization	11
Utilization Time(hh:mm)	10:20
Time at Speed (hh:mm)	8:36
% Idle Time	17%
Average Speed (mph)	25
%Time Speed>=40 mph	11%
N. Total Starts	79
%Accel Time	21%
% Decel Time	19%
% Cruise	43%

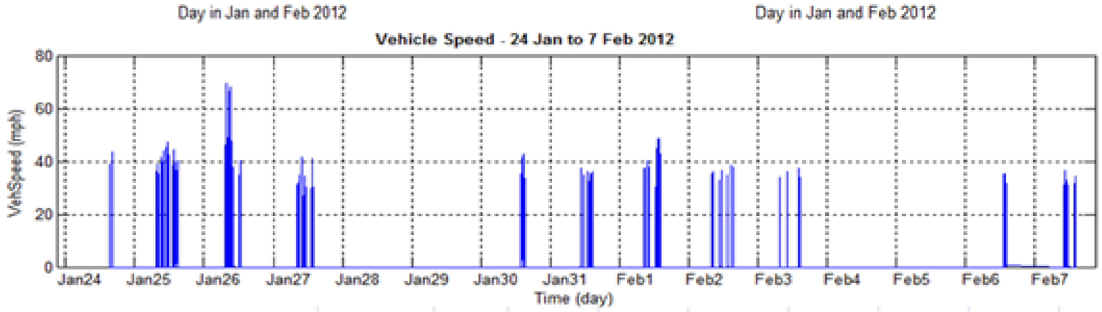








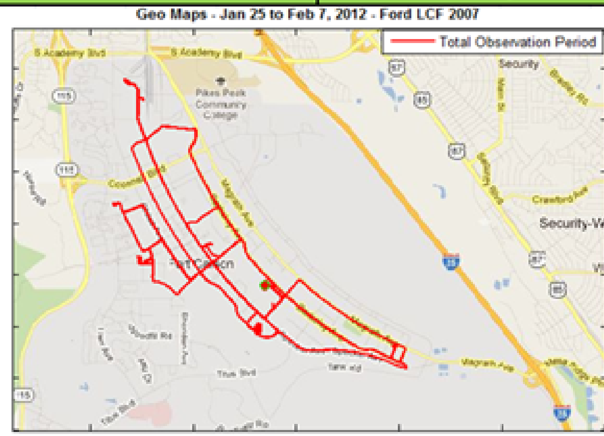


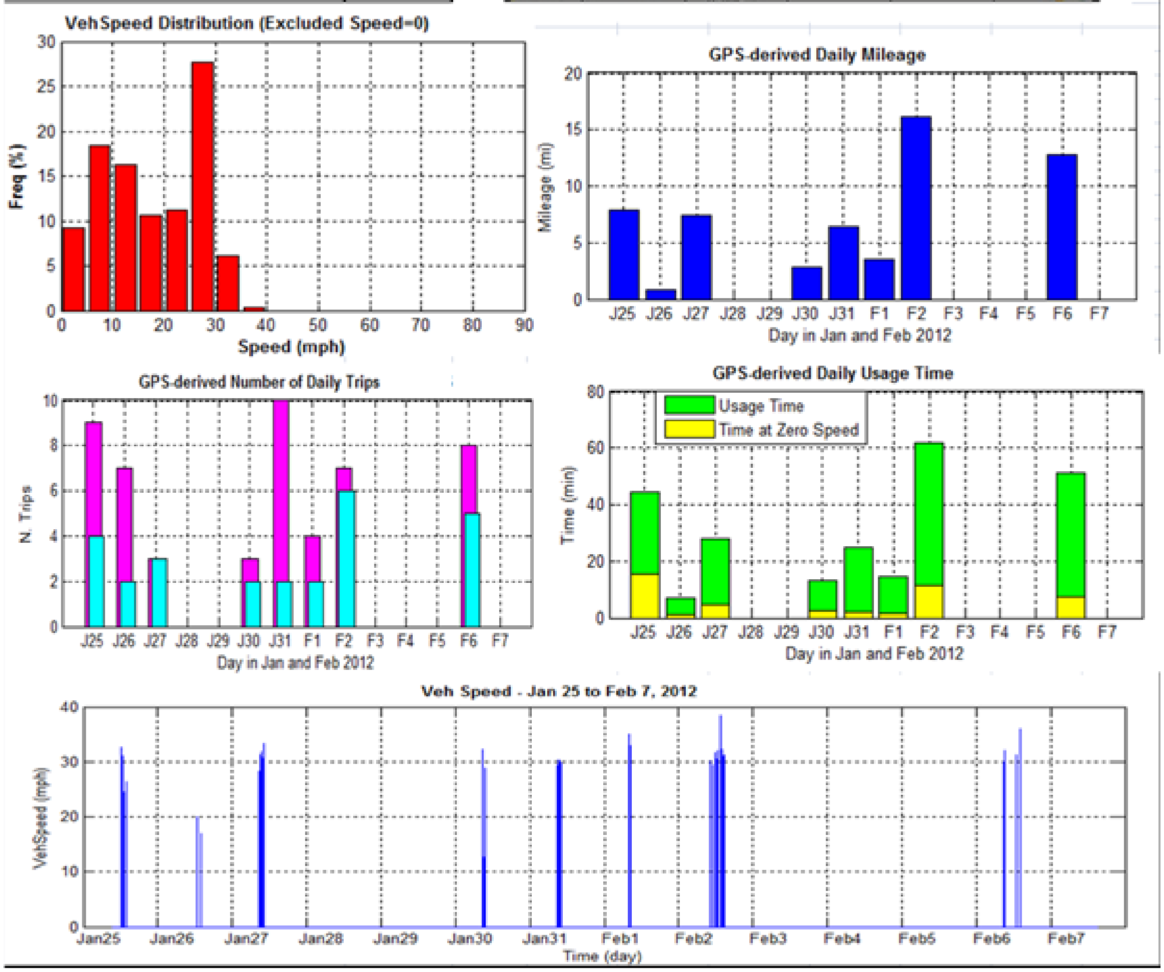


Notes. Round4 OBD logger.

	Observation Period 25-Jan-12 to 7-Feb-12
Total Mileage (mi)	57.9
Highest Daily Mileage (mi)	16.2
Observation Time (dd)	14
N. Days of Utilization	8
Utilization Time(hh:mm)	13:15
Time at Speed (hh:mm)	3:18
% Idle Time estimated	19%
Average Speed (mph)	17.8
%Time Speed>=40 mph	0%
N. Estimated Starts	52
%Accel Time	15%
% Decel Time	13%
% Cruise	53%

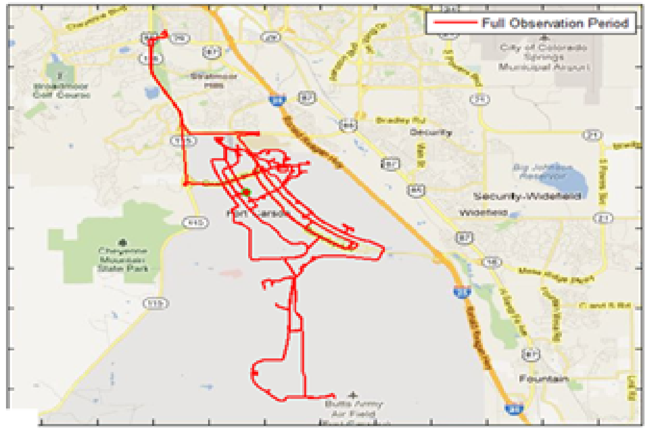
Flatbed Delivery - Ford LCF

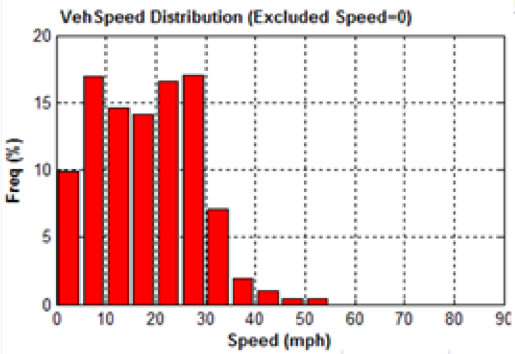


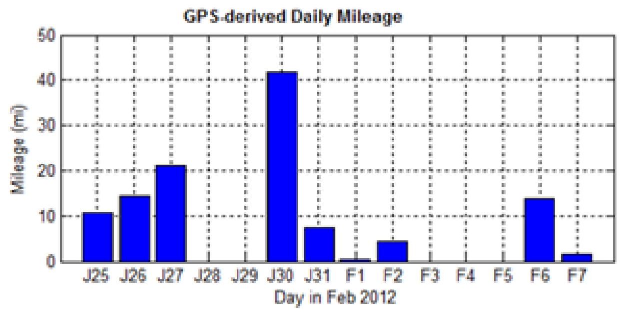


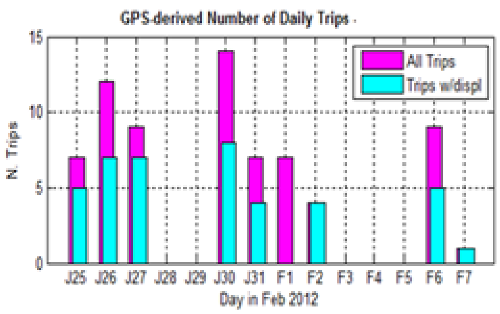
Notes. Round4 GPS Logger, dual data acquisition rate (every1 sec or ecery30 sec depending on motion). Idle estimated with a 120 sec cut-off.

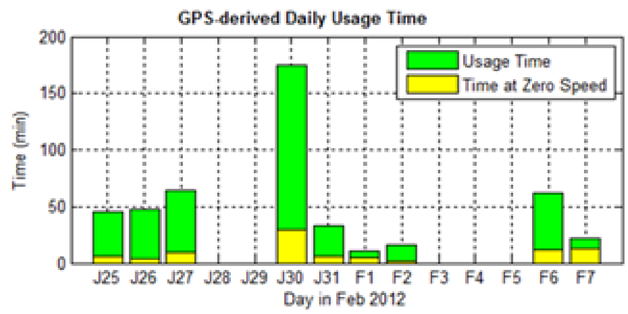
	Observation Period 25-Jan-12 to 7-Feb-12	Work Truck - Dodge Ram
Total Mileage (mi)	116	
Highest Daily Mileage (mi)	41.8	
Observation Time (dd)	14	
N. Days of Utilization	9	
Utilization Time(hh:mm)	7:54	
Time at Speed (hh:mm)	6:28	
% Idle Time	18%	
Average Speed (mph)	18.1	
% Time Speed>=40 mph	2%	
N. Estimated Starts	70	
%Accel Time	16%	
% Decel Time	15%	
% Cruise	51%	

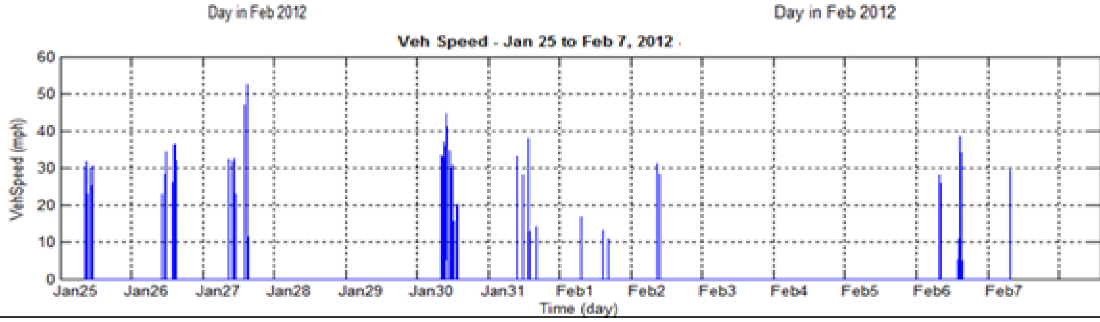






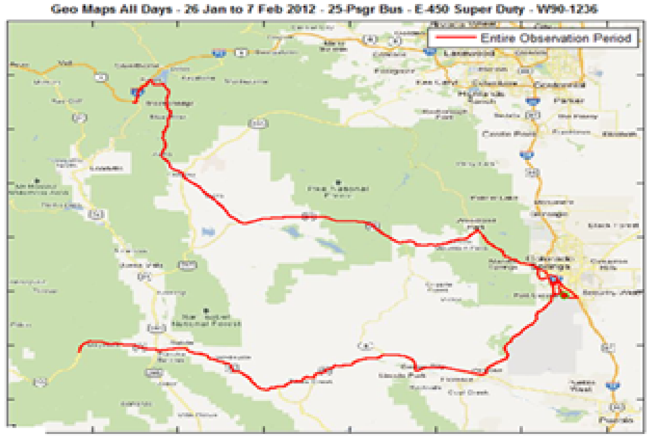


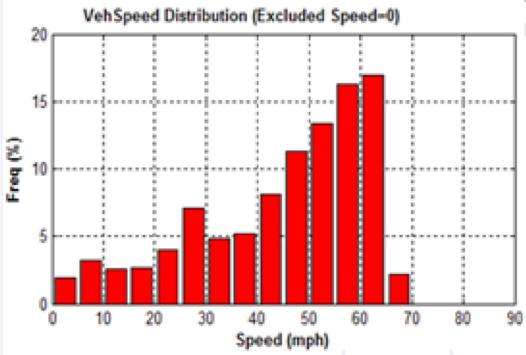


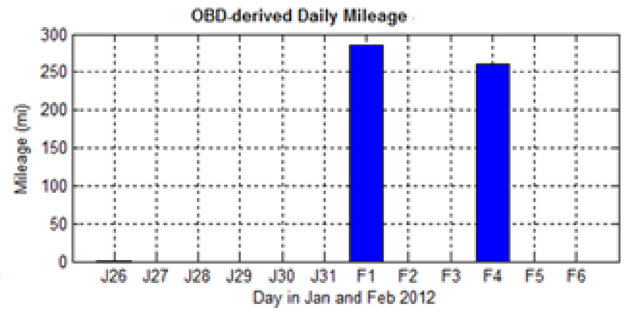


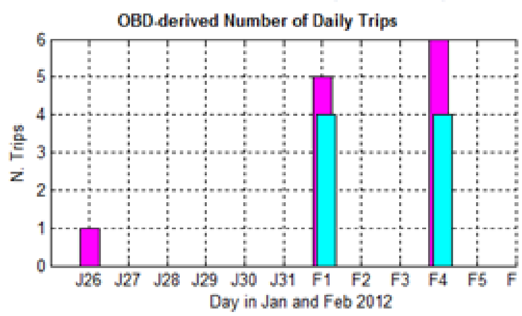
Notes. Round4 GPS Logger, dual data acquisition rate (every1 sec or ecery30 sec depending on motion). Idle estimated with a 120 sec cut-off.

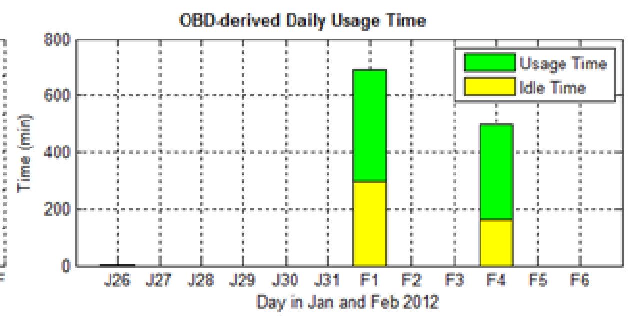
	Observation Period 26-Jan-12 to 7-Feb-12	25 Psgr. Bus - Ford E-450
Total Mileage (mi)	546	
Highest Daily Mileage (mi)	286	
Observation Time (dd)	13	
N. Days of Utilization	3	
Utilization Time(hh:mm)	19:50	
Time at Speed (hh:mm)	12:10	
% Idle Time	38%	
Average Speed (mph)	44.8	
%Time Speed>=40 mph	69%	
N. Total Starts	10	
%Accel Time	6%	
% Decel Time	6%	
% Cruise	50%	

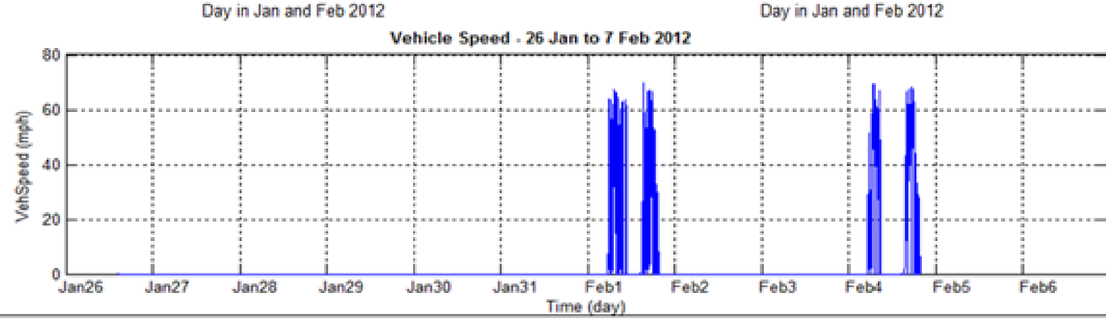






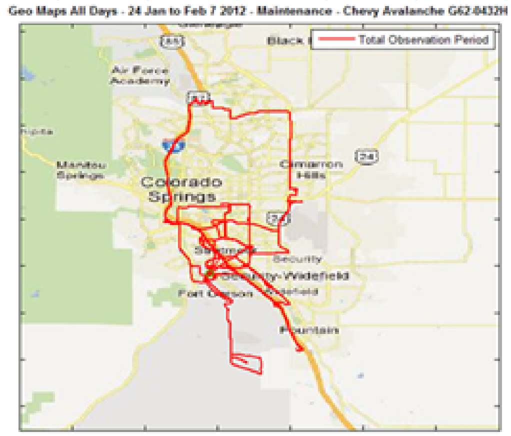


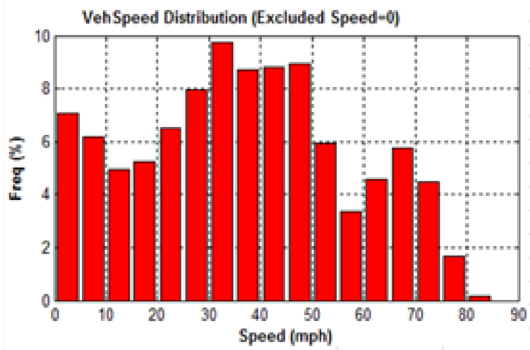


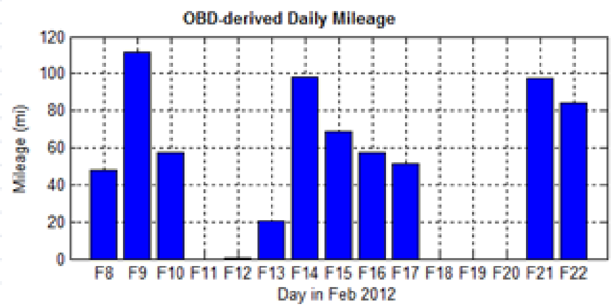


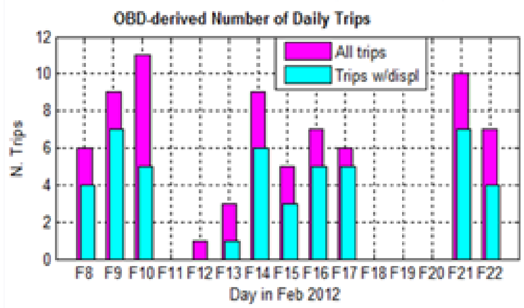
Notes. Round4 OBD logger.

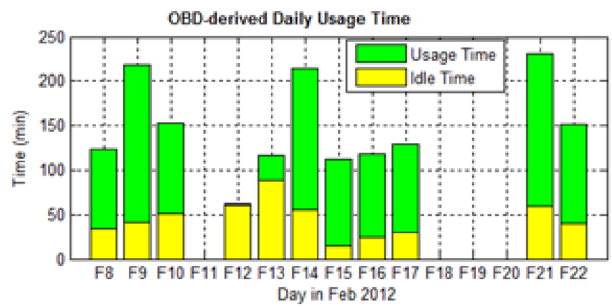
	Observation Period 8-Feb-12 to 22-Feb-12	Maintenance - Chevy avalanche
Total Mileage (mi)	694	
Highest Daily Mileage (mi)	111	
Observation Time (dd)	15	
N. Days of Utilization	11	
Utilization Time(hh:mm)	27:11	
Time at Speed (hh:mm)	18:54	
% Idle Time	30%	
Average Speed (mph)	37.6	
%Time Speed>=40 mph	44%	
N. Total Starts	74	
%Accel Time	16%	
% Decel Time	14%	
% Cruise	40%	

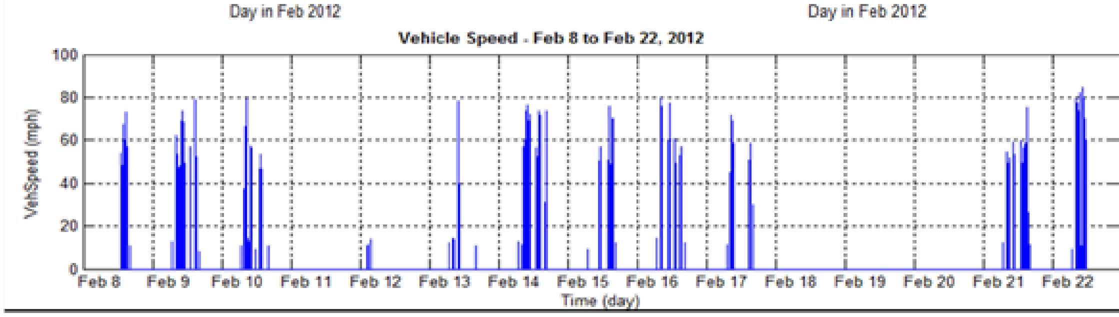






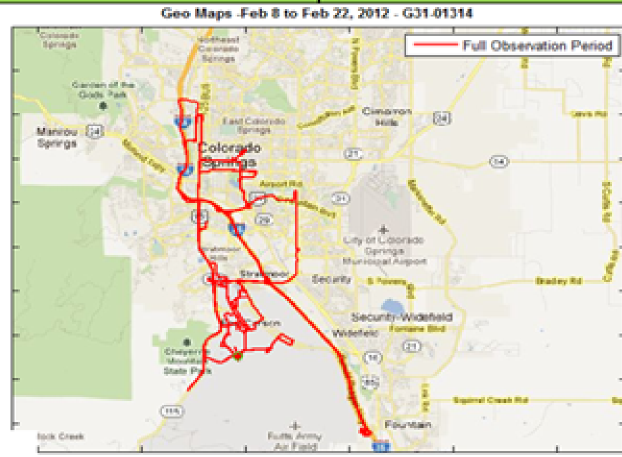


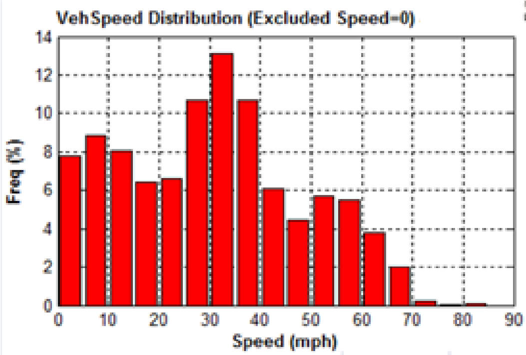


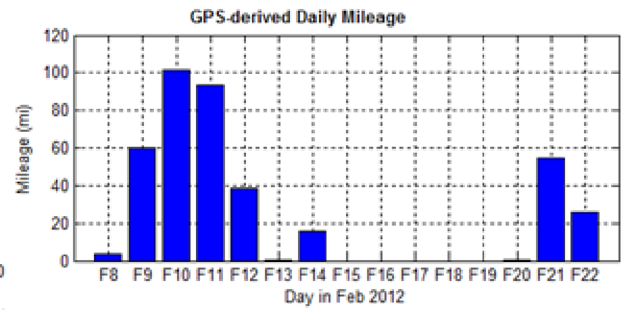


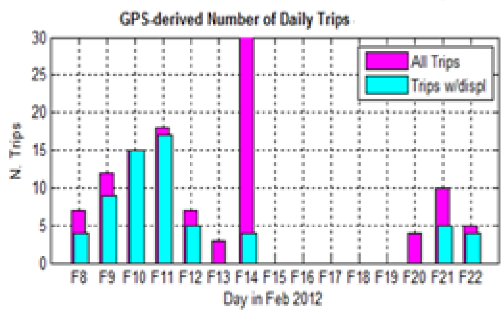
Notes. Round5 OBD logger.

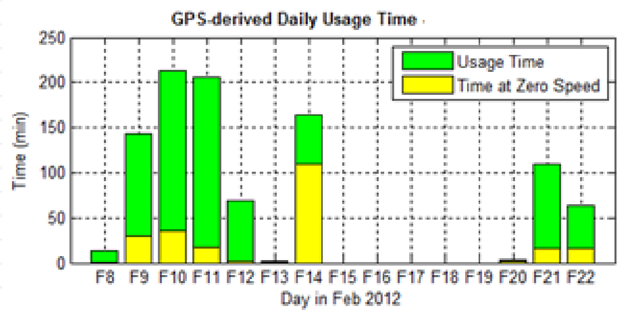
	Observation Period 8-feb-12 to 22-Feb-12	Ambulance - Chevy Kodiak
Total Mileage (mi)	394	
Highest Daily Mileage (mi)	102	
Observation Time (dd)	15	
N. Days of Utilization	8	
Utilization Time(hh:mm)	16:27	
Time at Speed (hh:mm)	12:36	
% Idle Time	23%	
Average Speed (mph)	30.6	
%Time Speed>=40 mph	28%	
N. Estimated Starts	142	
%Accel Time	17%	
% Decel Time	15%	
% Cruise	45%	

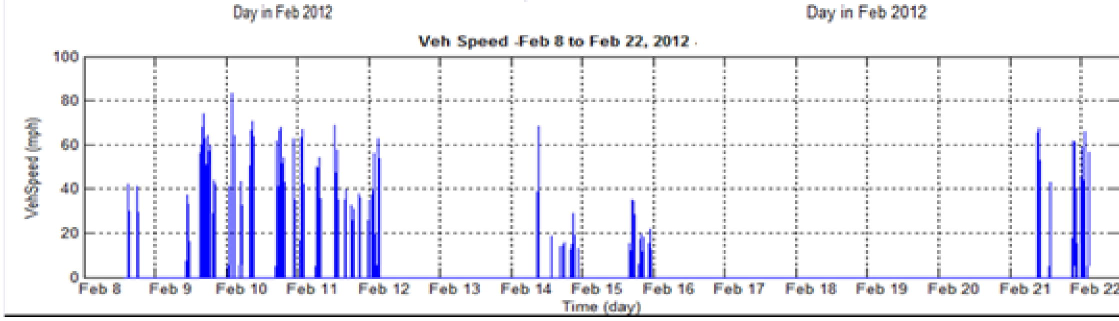






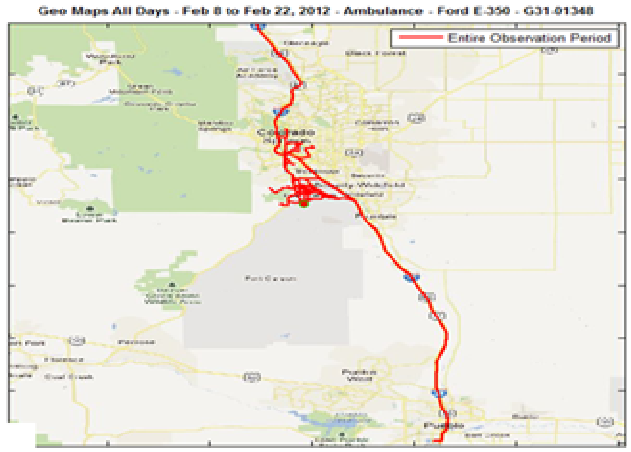


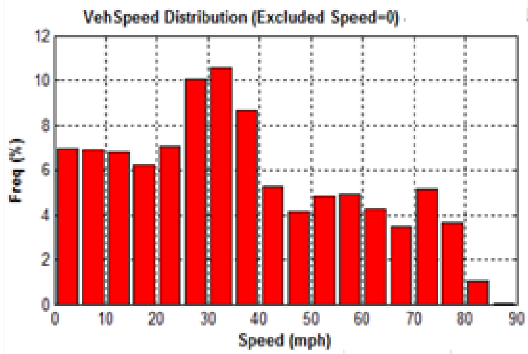


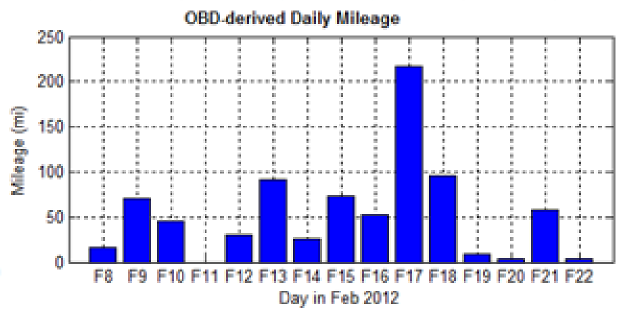


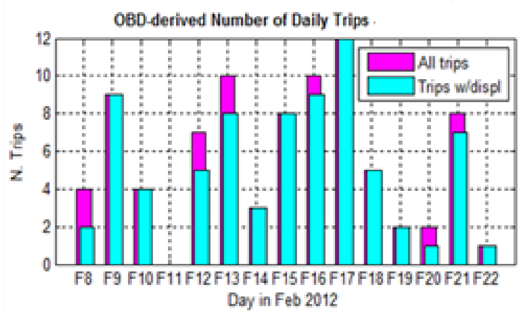
Notes. Round5 GPS Logger, dual data acquisition rate (every every 1 sec or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off.

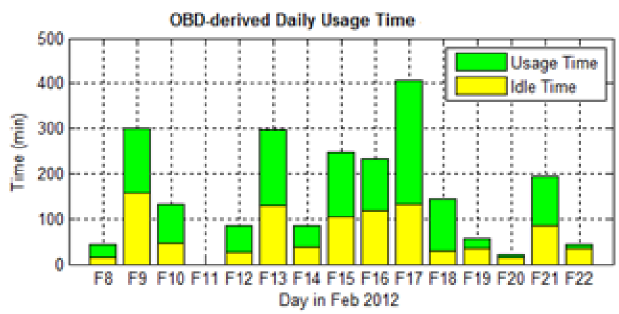
	Observation Period 8-Feb-12 to 22-Feb-12	Ambulance - Ford E-350
Total Mileage (mi)	789	
Highest Daily Mileage (mi)	217	
Observation Time (dd)	15	
N. Days of Utilization	14	
Utilization Time(hh:mm)	38:17	
Time at Speed (hh:mm)	22:08	
% Idle Time	42%	
Average Speed (mph)	35.6	
% Time Speed>=40 mph	37%	
N. Total Starts	85	
%Accel Time	13%	
% Decel Time	12%	
% Cruise	33%	

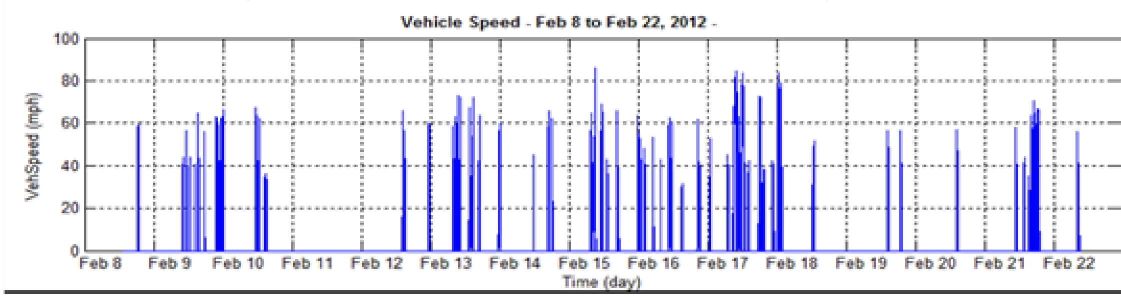






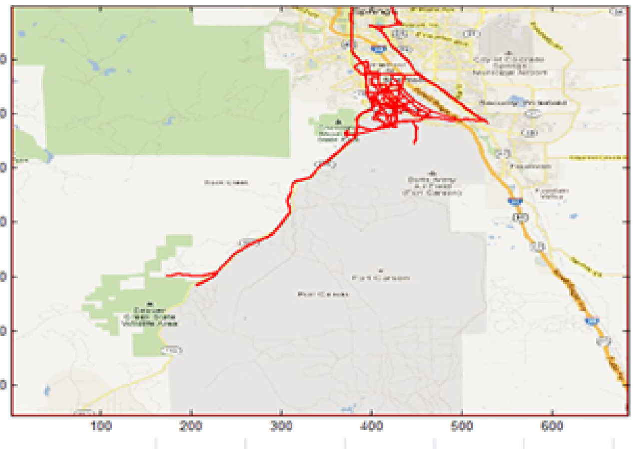


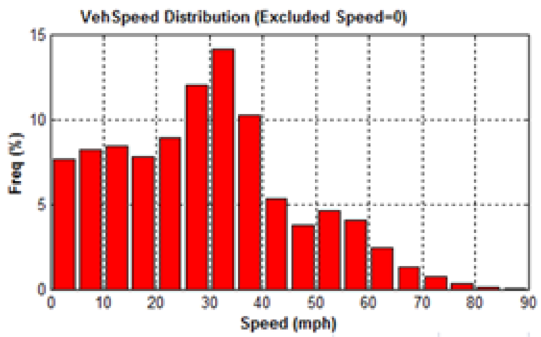


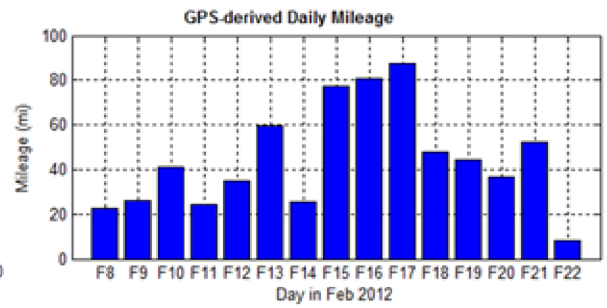


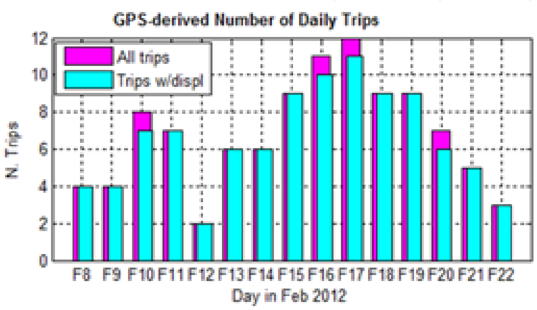
Notes. Round5 OBD logger.

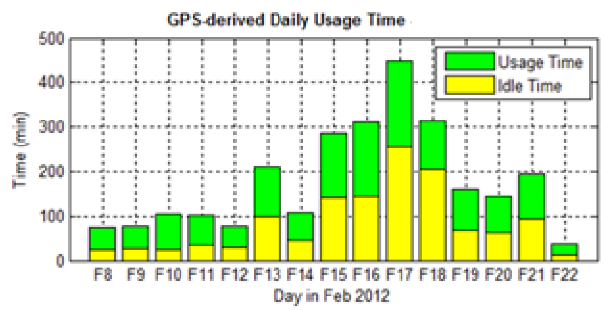
	Observation Period 8-Feb-12 to 22-Feb-12	Ambulance - Ford E-350
Total Mileage (mi)	669	
Highest Daily Mileage (mi)	87.6	
Observation Time (dd)	15	
N. Days of Utilization	15	
Utilization Time(hh:mm)	44:04	
Time at Speed (hh:mm)	23:01	
% Idle Time	48%	
Average Speed (mph)	29	
%Time Speed>=40 mph	23%	
N. Total Starts	102	
%Accel Time	12%	
% Decel Time	11%	
% Cruise	29%	

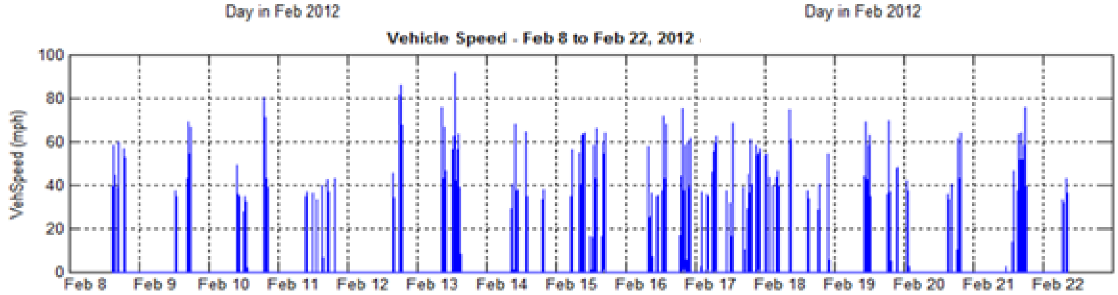








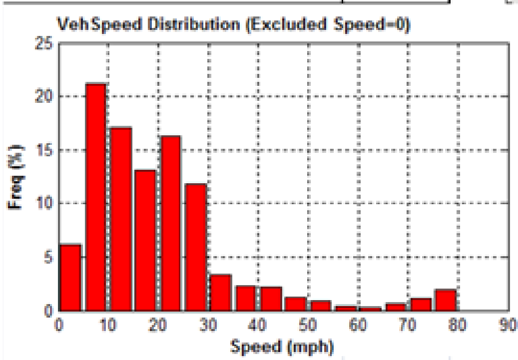


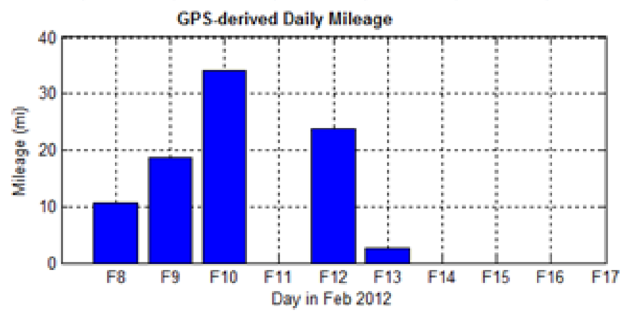


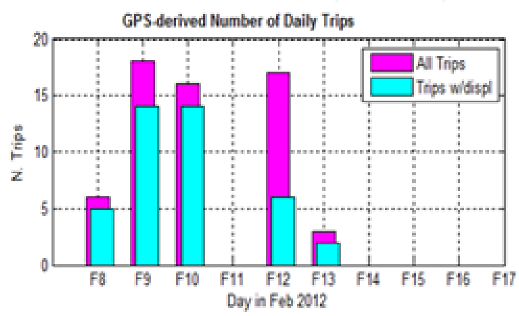
Notes. Round5 OBD logger.

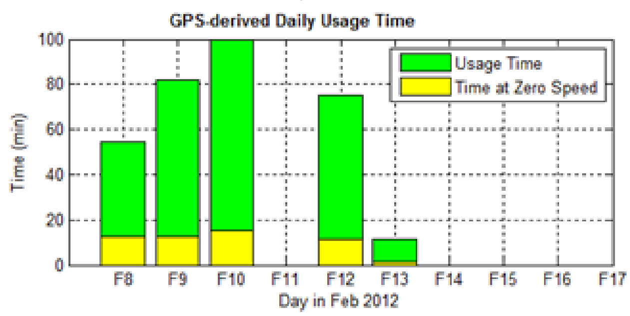
	Observation Period 8-Feb-12 to 12-Feb-12
Total Mileage (mi)	90
Highest Daily Mileage (mi)	34
Observation Time (dd)	6
N. Days of Utilization	5
Utilization Time(hh:mm)	5:22
Time at Speed (hh:mm)	4;29
% Idle Time	16%
Average Speed (mph)	20.2
%Time Speed>=40 mph	9%
N. Estimated Starts	60
%Accel Time	20%
% Decel Time	19%
% Cruise	44%

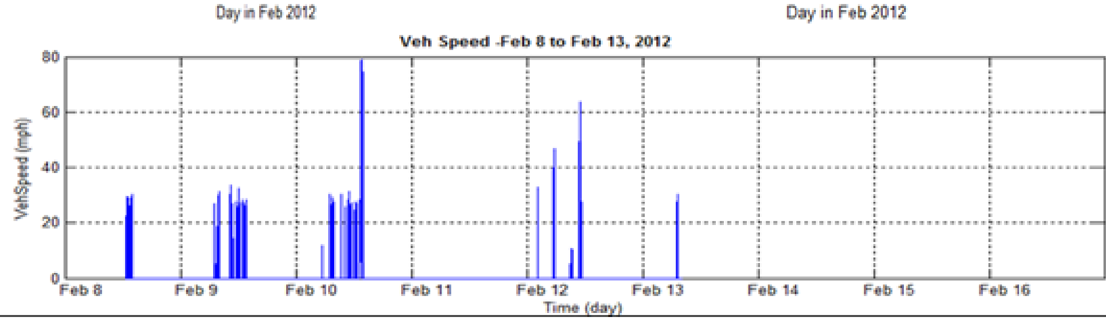
Bluebird Bus





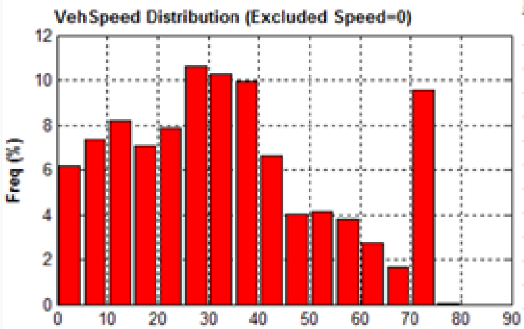


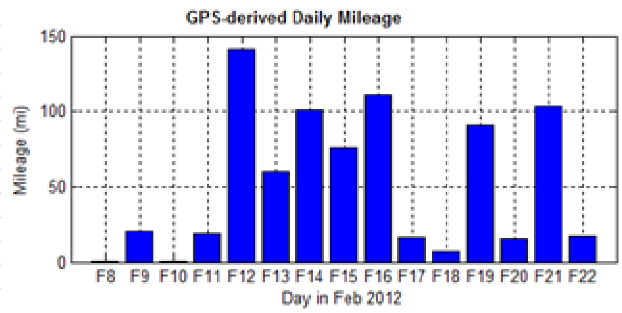


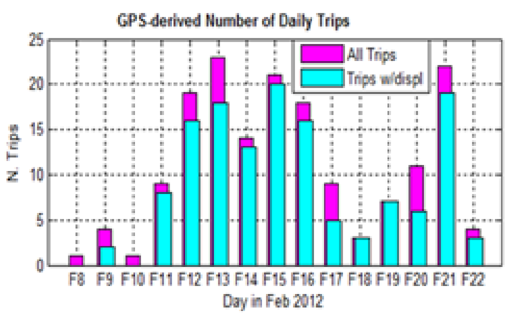


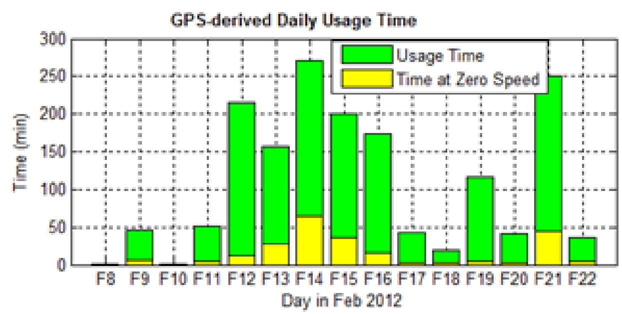
Notes. Round5 GPS Logger, dual data acquisition rate (every 1 sec or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off. Data acquisition halted midday on Feb 13 because the logger battery discharged.

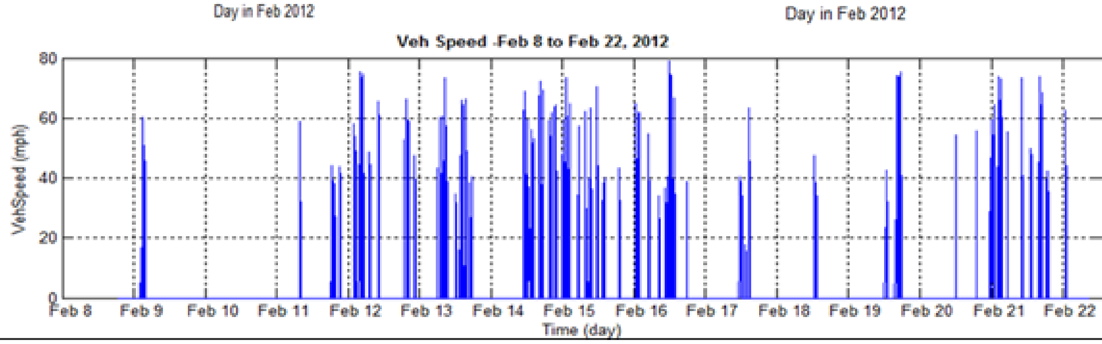
	Observation Period 8-Feb-12 to 12-Feb-12	Ambulance - Chevy 4500
Total Mileage (mi)	778	
Highest Daily Mileage (mi)	145	
Observation Time (dd)	15	
N. Days of Utilization	15	
Utilization Time(hh:mm)	27:00	
Time at Speed (hh:mm)	23:12	
% Idle Time	14%	
Average Speed (mph)	33.6	
% Time Speed>=40 mph	32%	
N. Estimated Starts	166	
%Accel Time	18%	
% Decel Time	18%	
% Cruise	50%	





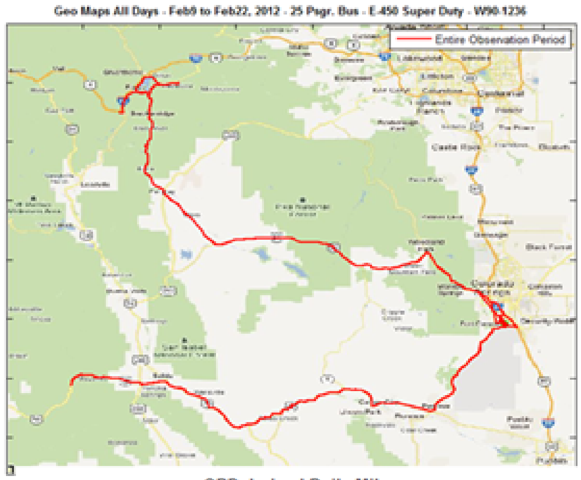


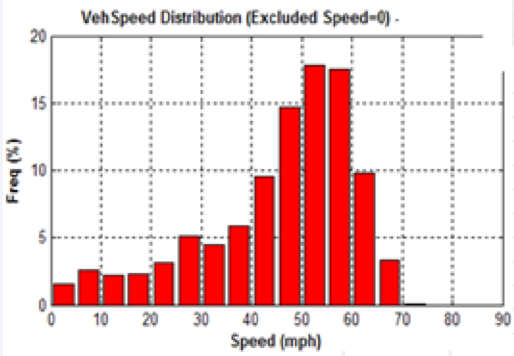


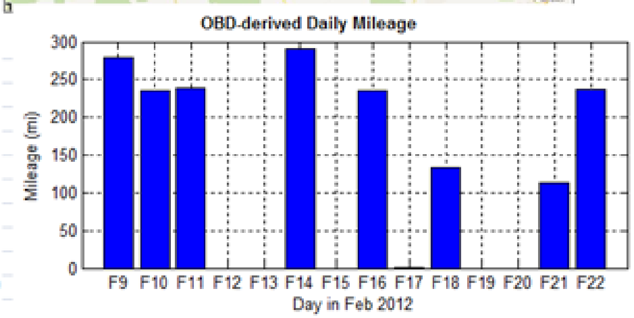


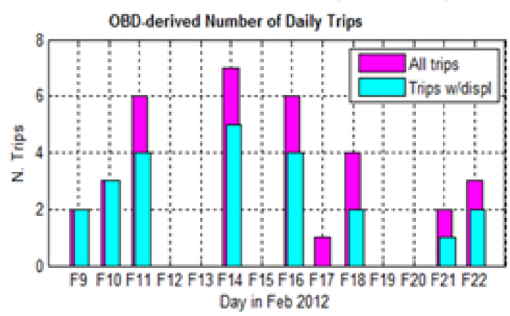
Notes. Round5 GPS Logger, dual data acquisition rate (every 1 sec or every 30 sec depending on motion). Idle estimated with a 120 sec cut-off.

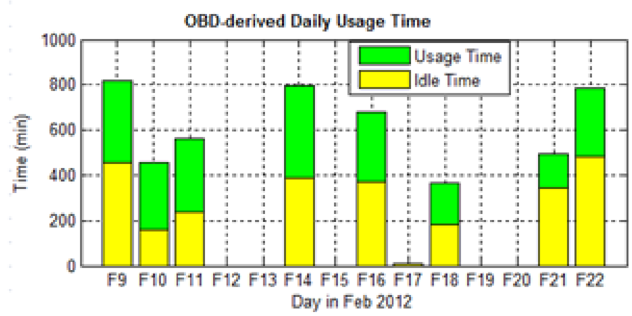
	Observation Period 9-Feb-12 to 22-Feb-12	25 Psgr. Bus - Ford E-450
Total Mileage (mi)	1761	
Highest Daily Mileage (mi)	290	
Observation Time (dd)	14	
N. Days of Utilization	9	
Utilization Time(hh:mm)	82:46	
Time at Speed (hh:mm)	38:40	
% Idle Time	53%	
Average Speed (mph)	45.5	
%Time Speed>=40 mph	72%	
N. Total Starts	34	
%Accel Time	4%	
% Decel Time	4%	
% Cruise	39%	

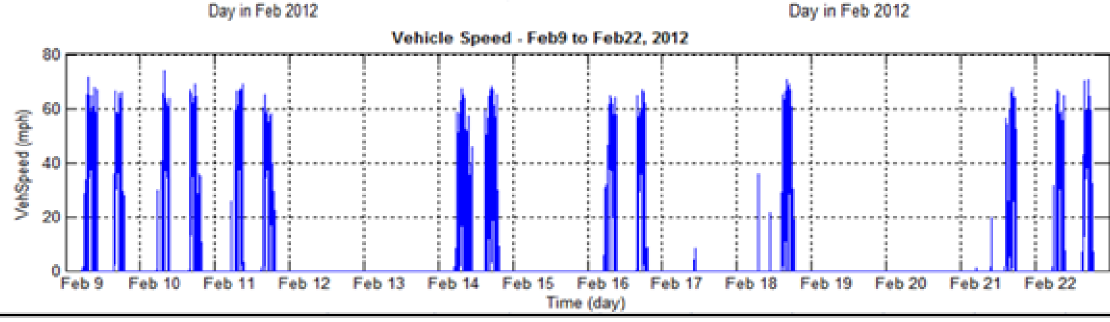












Notes. Round5 OBD logger.

3.4 Trip Statistics

The Geo Map plot provided in the Summary Report for each vehicle shows whether it operated only within the base or also outside the base. For on-base driving, the Vehicle Speed distribution typically shows an appreciable drop in the percentage of Speed values greater than 35 mph, which reflects the speed limit on the base. When the vehicle speed reflects approximately equal times spent within and outside the base, the speed distribution tends to develop a bimodal appearance. Separating vehicle speed values by location, it is possible to show that all vehicles monitored have the same qualitative speed patterns regarding the speed bin at which the cumulative sum crosses the 50% and the 75% mark. More precisely, the quartile values can be calculated.

While the Trip table indicating the Trip distance, length and maximum speed for each trip is too granular to perceive trends between vehicles, the mean and the median of the Trip distance and Trip Duration (Usage Time) can be valuable metrics for comparing driving profile characteristics. For example, the driving profile for one of the Ford F-250 work trucks monitored can be summarized at the trip level by the statistical parameters shown in Table 3 below.

Table 3: Statistical analysis of driving profile based on Trips – F-250 Work Truck

	N. Trips	153
	N. Trips>0.2 mi	135
Param	**Time(sec)**	**Distan(mi)**
average	430.4	1.7
median	385	1.5
1st Quartile	229	0.3
3rd Quartile	552	2.4
Max	1734	6.9
Min	4	0

The statistical analysis for this vehicle indicates that the distance travelled in 25% of the Trips is less than or equal to 0.3 miles with an average trip time of just under 4 minutes, while the distance traveled during 50% of the Trips (median value) is equal to or less than 1.5 miles with an average trip time of approximately 6.5 minutes. The average values of Time and Distance are larger than the median values which points to the existence of some longer Trips. However, the maximum Trip distance is still relatively short at only 6.9 miles. Thus, this vehicle could be a likely candidate for electrification.

Shown below in Figure 1 are the corresponding Trip Time and Distance distributions for this vehicle to illustrate that the Quartile parameters are better suited for direct comparison of duty cycles.

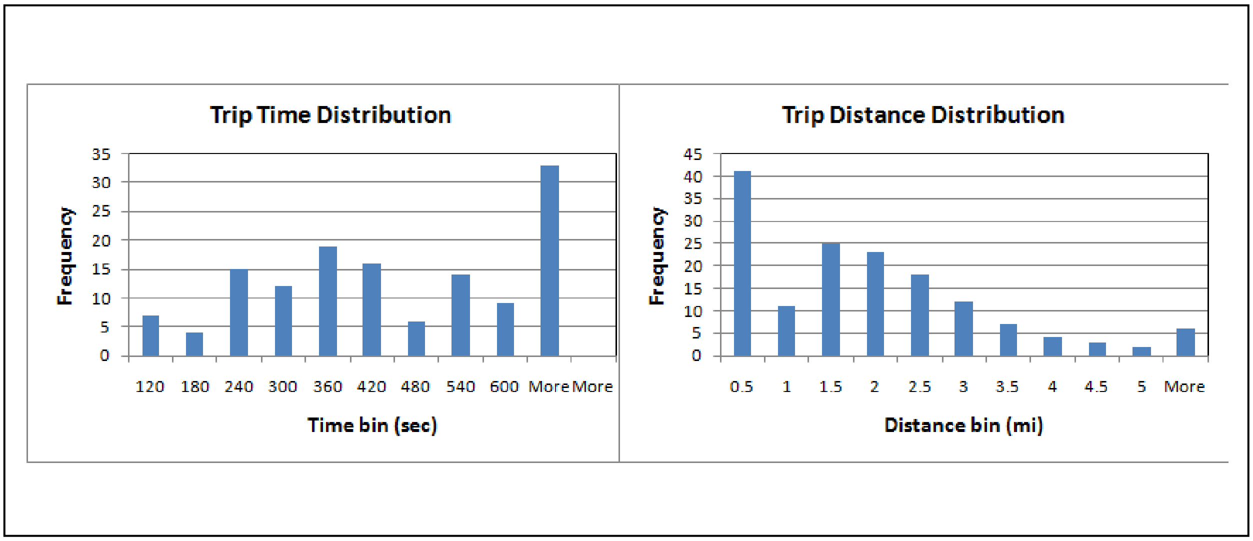


Figure 1: F-250 Trip Time and Distance Distributions

The statistical results in Table 3 correlate with the daily values of the Summary Report which show that the daily distance during a number of the days observed is approximately 30 miles, and is made up of short trips since number of trips ranges between 10 and 15. The two ways of summarizing duty cycle profiles are equivalent tools for understanding usage characteristics consistent with electrification benefit. In case the daily distance values are higher than the range for an electric vehicle, the quartile analysis may provide more insight on evaluating potential recharging issues.

Another useful input for electrification decisions is to understand exactly where and how far a vehicle travels relative to its home location on a daily basis. This information can be provided graphically by separating the two-week geo map trace shown in the Summary Report into daily segments. Daily geo maps for three selected vehicles have been plotted and are shown in Appendix E. Additional detail on individual trips has been provided by showing the trace for each trip during the day with a different color line, as well as tabulating the individual trip distances and durations. These collectively illustrate the mix of very short and medium length trips (about 5 to 6 miles) observed for these particular vehicles.

3.5 Energy Recovery Analysis

Energy recovery is also an important aspect for vehicle electrification. It is recognized that not all kinetic energy is recoverable as electric power into the storage medium during deceleration because of maximum current limitations at the high end and efficiency loss at the low end. However, if vehicles like the work trucks ranging from 4,000 to 6,000 lbs curb weight were to be electrified with a 50 kW power pack, they could derive substantial benefit from regenerative braking energy recovery. The mass of the vehicles monitored in this study was not known. However, some useful information may be calculated by looking at the change per unit time of a parameter, the vehicle velocity square (or VSS^2), which is proportional to kinetic energy loss (power) once the appropriate constant for the mass is factored in. If two vehicles can be assumed to have similar mass and loading with both driven on level ground, this parameter can be used as a comparison tool. A detailed justification for deriving this parameter is included in Appendix C.

The upper left chart in Figure 2 below shows the distribution of VSS^2 changes per second for a Ford F-250 work truck that operated primarily on the base. The distribution is skewed to low values indicating braking events from low speed as suggested by the vehicle speed distribution shown to the right. The VSS^2 distribution for a Dodge Dakota work truck that was also used on the highway and at higher speeds is shown in the lower left portion of Figure 2. This vehicle has a broader and more centered VSS^2 distribution.

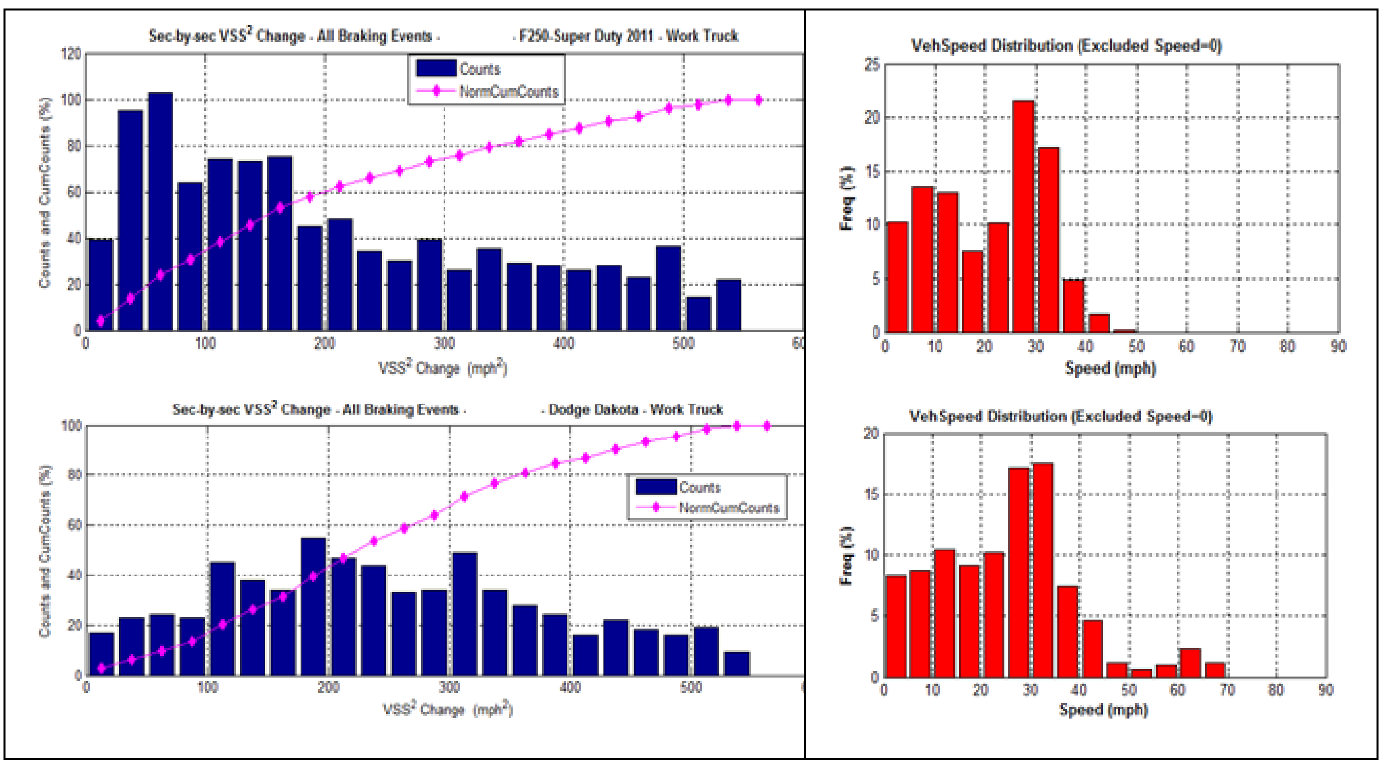


Figure 2: Distribution of changes in vehicle velocity per second squared referenced to vehicle speed distribution

4.0 Conclusions

Selected Fort Carson non-tactical vehicles were monitored for two-week periods utilizing either GPS data loggers or OBD-II data loggers with GPS capabilities to extract duty cycle information. Data was acquired in the form of data series which enabled statistical analysis of the driving profile described by means of Global Parameters plus evaluation of driving characteristics with a finer scale on a daily basis. This is important for assessing recharging issues if these vehicles were to be electrified.

The types of vehicles monitored can be grouped into those that operate mainly within the base and its immediate proximity (work trucks, maintenance and delivery vehicles) and the ones that may make long trips away from the base, sometimes with overnight rest (pool vehicles, ambulances and shuttle vans). Table 4 below shows key metrics summarizing vehicle usage for each of the vehicles monitored, grouped in functional categories.

Table 4: Vehicles monitored with key metrics and operating areas

Function	No. Util. Days	Time at Speed (hh:mm)	Total Mileage (mi)	Highest Daily Mileage (mi)	Percent Idle Time (%)	No. trips	Avg Spd (mph)	Operational Location
Engineering	12	13:17	226	36	23	94	22.5	Base/City
Maint/Supply Activ	9	8:40	244	67	15	65	28.5	Base/City
Maint/Supply Activ	10	9:06	193	37	14	97	21.0	BaseCtr
DPW Fleet Mgr	11	8:34	171	38	26	93	19.9	BaseS/City
Maintenace	11	18:54	694	111	30	74	37.6	Base/City
Pool	11	27:24	1491	314	11	147	54.5	Base/South
Pool (Exec. Van)	7	15:41	958	332	6	42	61.3	Base/NM
Work Truck	15	21:28	494	54	12	165	23.2	Base/South
Work Truck	7	6:06	184	73	20	78	30.0	Base/South
Work Truck	13	12:16	253	30	33	153	20.6	Base
Work Truck	11	9:25	199	66	11	113	21.4	Base/BaseSo
Work Truck	11	14:37	319	51	22	157	21.8	Base/City
Work Truck	11	8:36	215	66	17	79	25.0	Base/BaseSo
Delivery Flat Bed	8	3:18	58	16	19	52	17.8	Base
Work Truck	9	6:28	116	42	18	70	18.1	Base/City
Ambulance	17	15:15	372	52	10	116	30.5	Base/City
Ambulance	8	12:36	394	102	23	142	30.6	Base/City
Ambulance	14	22:08	789	217	42	85	35.6	Base/Pueblo/Denver
Ambulance	15	23:01	669	88	48	102	29.0	Base/BeaverCr./City
Ambulance	15	23:12	778	145	14	166	33.6	City/Pueblo
25-Psgr Bus	1	5:56	273	273	2	7	47.3	WestRange
25-Psgr Bus	3	12:10	546	286	38	10	44.8	Mountains
Transport Bus	5	4:29	90	34	16	60	20.2	Base/City
25-Psgr Bus	9	38:40	1761	290	53	34	45.5	Mountains

4.1 Summary Trends by Vehicle Functional Type

The frequency and intensity with which the Fort Carson NTVs monitored in this study were utilized showed substantial day-to-day differences. There are summary trends that can be identified across the various vehicle functions that help to quantify their potential for replacement with electrified vehicles. The following are key electrification observations for the vehicles grouped into five primary functional categories.

Support Vehicles: Engineering, Maintenance/Supply, DPW Fleet Mgr

- The five vehicles monitored were utilized nearly every work day on the base or in the adjacent city area but rarely on weekends or for longer trips. Number of trips averaged 7 – 10 per day.
- Average daily mileage was 16 – 27 per day for four of the vehicles, and 63 for a maintenance vehicle that spent significantly more time than the others off base.
- Highest single day mileage was 36 – 38 miles for three vehicles, 67 for one and 111 for the one with the higher time off base.
- Average speed was below 30 mph for the four vehicles that spent most of their time on base and 37.6 mph for the other.

- Percent idle time was relatively high for these vehicles, ranging from 14 – 30%. The winter observation periods could be a contributing factor if vehicles were warmed up.
- Overall this group of vehicles appears to contain good candidates for electrification due to their usage on or near the base and low daily mileage. The rationale for the higher mileage on the one maintenance vehicle would need to be better understood.

Pool Vehicles

- Two pool vehicles were monitored and both experienced high mileage and high speed usage on trips ranging far away from the base. One went to the Army's Piñon Canyon training facility in southern Colorado while the other (a 12-psgr executive shuttle van) went to Santa Fe, New Mexico.
- A closer look at daily usage reveals a bipolar distribution. The pool vehicle experienced usage of over 150 miles on six of eleven usage days, but under 50 miles on the other five. The shuttle van had three usage days out of seven where it recorded around 300 miles, but less than 10 miles per day on the other four.
- Idle time ranged from just 6 – 11%, in part due to the high time at speed.
- This variable usage suggests there is an opportunity to have some pure EVs as pool vehicles that can be checked out for local trips on or around the base, but there is still a need to have PHEVs, charge-sustaining HEVs, or conventional vehicles available that are capable of long distances in a single day.

Work Trucks

- These eight vehicles are mostly box trucks on a light or heavy-duty pickup chassis plus one flat bed delivery truck. They are typically used to transport an operator and tools to on-base locations for maintenance and repair.
- They make frequent short trips, averaging around 10 trips per day. They are used mostly between 07:00 and 16:00 on weekdays, and tend to return to their primary storage location at night. They are rarely used on weekends.
- Average daily mileage ranged from 7 – 33 miles (20 miles avg.), while highest single day usage ranged from 16 to 73 miles, depending on whether a truck travels to the southern part of the base.
- Average speed ranges from 18 – 30 mph, governed largely by the base speed limit.
- Idle time ranges from 11 – 33% with an average of 19%.
- This group of vehicles appears to contain the best candidates for electrification of all the vehicles monitored. Usage is primarily on the base, they return to a central location nearly every night, and average daily mileage is low with a highest single-day usage of just 73 miles.

Ambulances

- Four ambulances were monitored over five periods (one was revisited with an OBD logger due to initial GPS logger data anomalies). They tend to be used seven days per week but the number of trips per day is highly variable, ranging from 0 to over 20.

- Average daily mileage was over twice that of the work trucks, at 45 miles. These vehicles also experienced some longer trips, with three having highest single day mileage over 100 miles and one over 200 miles when it went to Denver.
- Idle time was also highly variable, ranging from 10% to 48%. The higher figure would be consistent with an ambulance running its engine at an emergency site in order to power on-board equipment.
- This group of vehicles appears to have less potential for electrification due to the duty cycle and need for longer distance capability.

Transport and Shuttle Buses

- Of the four vehicles were monitored, the three 25-passenger shuttle buses tended to have lower usage, averaging 3 – 7 trips per day. The Bluebird transport bus averaged 12 trips per day on the five days it was used with a high of 18.
- The shuttle buses recorded much higher distance, however, with highest single day usage for all three ranging from 273 – 290 miles. All three were used for trips to ski resorts in central Colorado.
- The highest single day usage on the Bluebird bus was just 34 miles, and all operation was either on base or in the nearby Colorado Springs area.
- Idle time on one of the 25-passenger buses was very low (2%) but ranged from 38 - 53% for the other two. The Bluebird bus idled just 16% of the time.
- The duty cycle for the Bluebird bus appears to make it a good candidate for electrification, perhaps with one of the PHEV transport buses from IC Bus that is on the GSA schedule. The 25-passenger shuttle buses must travel much greater distances into the mountains of Colorado at higher speeds and with less predictable schedules. There are PHEV shuttle buses now available that could be replacement candidates.

Appendix A: Data Pre-Processing Methodology

Several steps were required to reformat the raw data into an appropriate input data set for the duty cycle analysis, as described below.

The raw data for each vehicle, collected as time series, were first checked for skips and cleansed of obvious outliers. Gaps were filled by linear interpolation. The vehicle speed derived from GPS coordinates contains some level of noise which can result in a non-zero velocity even if the vehicle is stationary, contaminating the mileage calculation. As a result, a cut-off threshold of 0.5 mph was typically used to define the vehicle as stationary. In some cases the threshold had to be increased to as much as 2.0 mph when the unit was not in good communication with GPS satellites, such as when the vehicle was inside a building.

For calculating overall mileage and utilization-time duty cycles, the input data for the processing algorithm had to be in the form of a single 2-D array. GPS data were already in this format, but for OBD data it was necessary to merge the files generated for each engine start and combine the data into two 2-D arrays, one for the Position (GPS) and another for the Engine data. The arrays cannot be combined directly since the OBD data rate is faster than the GPS rate.

For certain comparisons, it is valuable to tabulate the number of times the vehicle starts on a new journey (or Trip) rather than counting each period during which the vehicle is moving (microTrip). OBD-derived data readily provide the start and the end of a Trip as explained earlier. However, since the GPS logger generates a continuous recording, the start and the end of a Trip needs to be estimated. The key assumption for this estimation is that during periods when the vehicle is stationary for less than 120 sec, the engine was kept running since the vehicle was continuing on its journey. OBD-derived data have been used to support the validity of this assumption as shown separately in Appendix B. However, any Idle Time before the first movement or after the last stop cannot be obviously inferred. In this way, segmentation of the GPS data into Trips has been carried out providing an estimate for the number of starts, Idle Time and the rest period between Trips.

One other data pre-processing operation consisted of defining a continuous timeline for each data array with reference to 24:00 (Fort Carson local time) on the day when data were first acquired. This timeline is necessary only when analyzing and plotting speed traces to assess during which portion of the day the vehicle is actually being driven. In the case of data collected with the OBD logger, the timeline is also needed to verify consistent time-alignment between GPS derived and OBD-derived speed traces to ensure that geographic location information matches daily duty cycles. This is important since the duty cycle calculations were carried out relying on OBD-derived speed values since GPS recordings were found to often have delayed starts and numerous skips which would have contaminated the duty cycle results.

Data processing was carried out in MATLAB because of the large data set size (the array length ranges from 100,000 to nearly one million). Geo Maps were also created within this environment because the IOSiX devices did not include a method for reformatting the data for direct import into Google Maps.

Appendix B: Idle Time Considerations

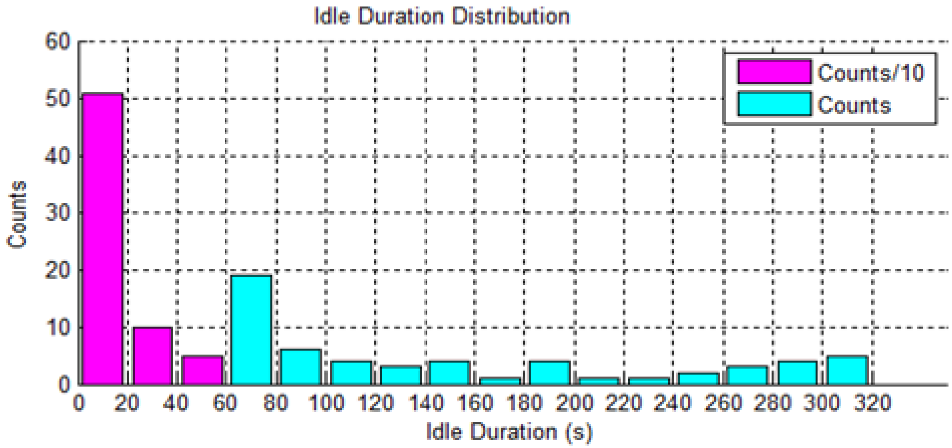
An important factor in understanding whether a vehicle can be replaced with an electrified one is whether the engine is run at idle for extended periods, perhaps to provide power at a job site or provide climate control functions. The OBD-II port loggers utilized in the study were capable of detecting whether the engine was running when the vehicle was at rest, but the GPS loggers were not. The GPS loggers were programmed to change their sampling rate from every 1 second to every 30 seconds when the vehicle came to rest in order to conserve memory. As soon as the vehicle started moving again, the vibration sensor incorporated in the logger would trigger it to resume recording at the faster rate. Thus, the actual data might show a gap from 2 seconds up to 29 seconds if the vehicle started moving before the 30 second mark, or show several data points taken every 30 seconds.

For the purpose of evaluating where and how a vehicle travels, it is useful to think in terms of Trips (a Trip being identified as the time from Engine-On to Engine-Off). Keeping track of each segment of vehicle motion separately can not only be unwieldy, especially during city driving or in an environment like Fort Carson with many stop signs, but does not allow evaluation of certain stop-and-go features of the driving profile which are relevant to understanding electrification benefits.

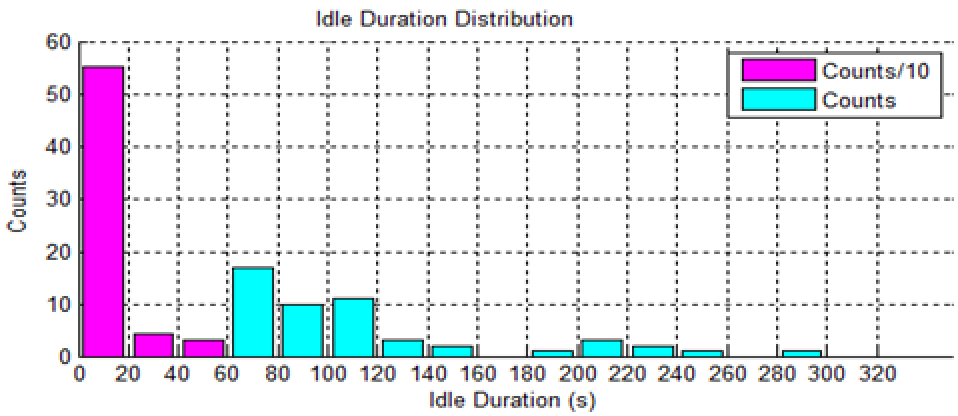
Given the limitations of the GPS loggers, the analysis has incorporated a way of estimating, counting and keeping track of periods of rest during which the engine is likely idling. The estimation is based on assuming that every time the vehicle is at rest for up to 120 seconds or more, the engine has been turned off. The 120 second threshold was chosen because Fort Carson has an Idle Time limit of 120 seconds. When data from the OBD-II loggers became available, this assumption was validated as explained below.

The duration of Idle Segments derived from the vehicle speed time-series obtained from the OBD-II port loggers were tabulated. Examples of Idle Time duration are shown below in Figure 3 for three vehicles with different functions, an ambulance, a work truck and a 25-passenger bus. Approximately 90% or more of Idle Periods are less than or equal to 120 seconds (actual numbers shown in figure captions) and a small number of idle periods longer than 320 seconds were observed (the ambulance had the longest Idle periods). Importantly, there is no evidence for engine restart occurring before 120 seconds from shut-down. The three shortest restart separation times are also given in Figure 3 below.

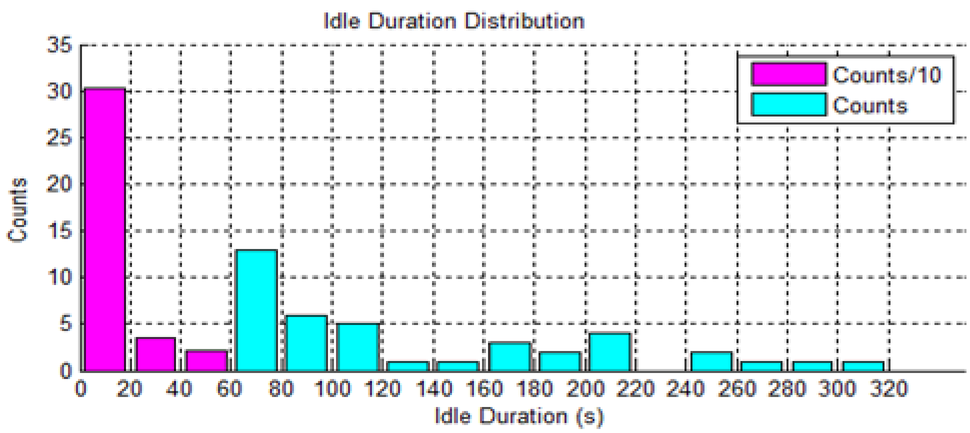
Idle Time is reported in the Summary Report both for OBD-II logger-derived data (actual measurements) and for GPS logger-derived data, estimated with the 120 second cut-off limit. This method underestimates the true Idle Time because there is roughly a 10% probability that longer idle periods could have existed. Moreover, the method cannot estimate Idle Time when the engine is first started or after the last segment of motion for the vehicle. An attempt to identify start-up Idle Time has not been made for the GPS logger data.



Ambulance: 89% are segments <=120 sec, 7% are >320 sec. Shortest restart separations are 237, 820, and 1041 sec.



Work Truck: 96% are segments <=120 sec, 2.5% are >320 sec. Shortest restart separations are 142, 358, and 373 sec.



25-Passenger Bus: 96% are segments <=120 sec, 1.4% are >320 sec. Shortest restart separations are 151, 221, and 624 sec.

Figure 3: Idle Duration Analysis for Three Types of Vehicles

Appendix C: Kinetic Energy Considerations

Electrified vehicles rely on the translation of kinetic energy into electrical energy for recovery into a storage mechanism (regeneration) as a key element of their overall efficiency. The potential kinetic energy available for recovery is thus an important consideration in vehicle electrification decisions. In this particular study, neither the mass of the vehicles monitored was known nor was the payload they typically carry, so kinetic energy could not be calculated directly.

In order to provide useful information to TARDEC from the available data, the deceleration profiles were analyzed to extract a metric from which to estimate whether the vehicle deceleration profile has characteristics consistent with the ability of a power pack to efficiently absorb the energy generated during braking. In other words, a metric has been defined that produces a distribution of the changes in unit time of the square of the vehicle velocity so that vehicles of similar mass can be qualitatively compared. Use of a distribution allows best/worst scenario types of energy recovery estimates to be done by selecting a suitable range of bins in the distribution. In practice, this method means extracting from each braking event equivalent segments from an energy perspective, regardless of the initial value of the vehicle velocity and deceleration.

The Summary Report for each vehicle monitored includes information on vehicle acceleration, deceleration, and cruise duty cycle as a function of total drive time. These were calculated as the percentage of time the vehicle longitudinal acceleration is, respectively, either greater than a positive threshold value *AccThld (% Time Accel*), or less than a negative threshold value –AccThld *(% Time Decel*), or lies in between *(% Time Cruise*). The additional condition that the Vehicle Speed is greater than zero was imposed to exclude Idle data points in the calculation of these three parameters.

Figure 4 below illustrates how the vehicle speed profile during one Trip is segmented using the above criteria. In the upper graph, the Vehicle Speed data, measured every 1 second, are plotted as a function of time. The lower graph shows the Acceleration trace calculated as the speed change over 1 second (blue line) and after a 2-point averaging (red dot line). The colored dots in the upper graph identify acceleration, deceleration, cruise and idle segments which are differentiated by using a vehicle acceleration threshold AccThld = 0.08 mph/s for the filtered acceleration and of opposite sign for the accel/decel cases. Cruise includes points for which the Acceleration is = 0 but the Vehicle Speed >0. The Acceleration and Deceleration Thresholds are shown in the lower graph in Figure 4.

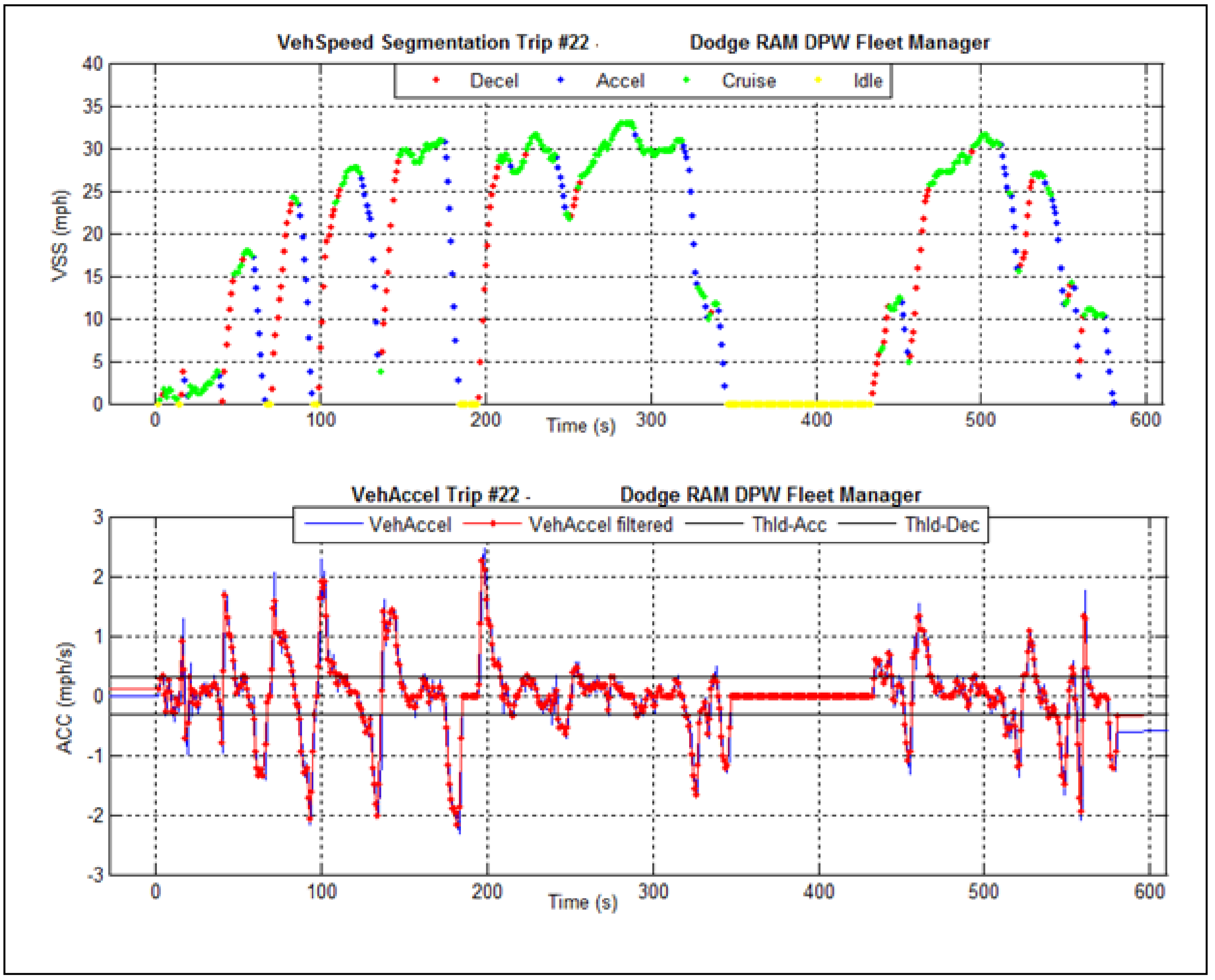


Figure 4: Vehicle Speed Trace with Corresponding Acceleration/Deceleration Plot

Figure 5 below shows the same velocity profile as in Figure 4 with the start-point and the end-point of each deceleration segment highlighted. Segments lasting <= 2 sec have been excluded. Evaluation of the Throttle Position (TP) signal supports that these deceleration segments, defined by means of the acceleration threshold value shown in Figure 4, correspond to Tip-out conditions. These segments are referred to as Braking Events, even though there is not direct information on the brake pedal application. The Kinetic Energy change during the Braking Event is proportional to the difference of the initial velocity square and the final velocity square (*delVSS^2*).

The stem plot at the bottom of Figure 5 gives values proportional to the change of Kinetic Energy during each event. As expected, braking events starting at higher speeds produce

larger energy changes. Thus, an estimate of the upper limit for the energy that can be harvested during a Trip (or an entire driving cycle) is proportional to

$$VSquareLoss = \sum_n (Vin_n^2 - Vfin_n^2) = \sum_n delVSS^2$$

where *n* counts Braking Events over the cycle. The proportionality factor is the Vehicle Mass divided by 2.

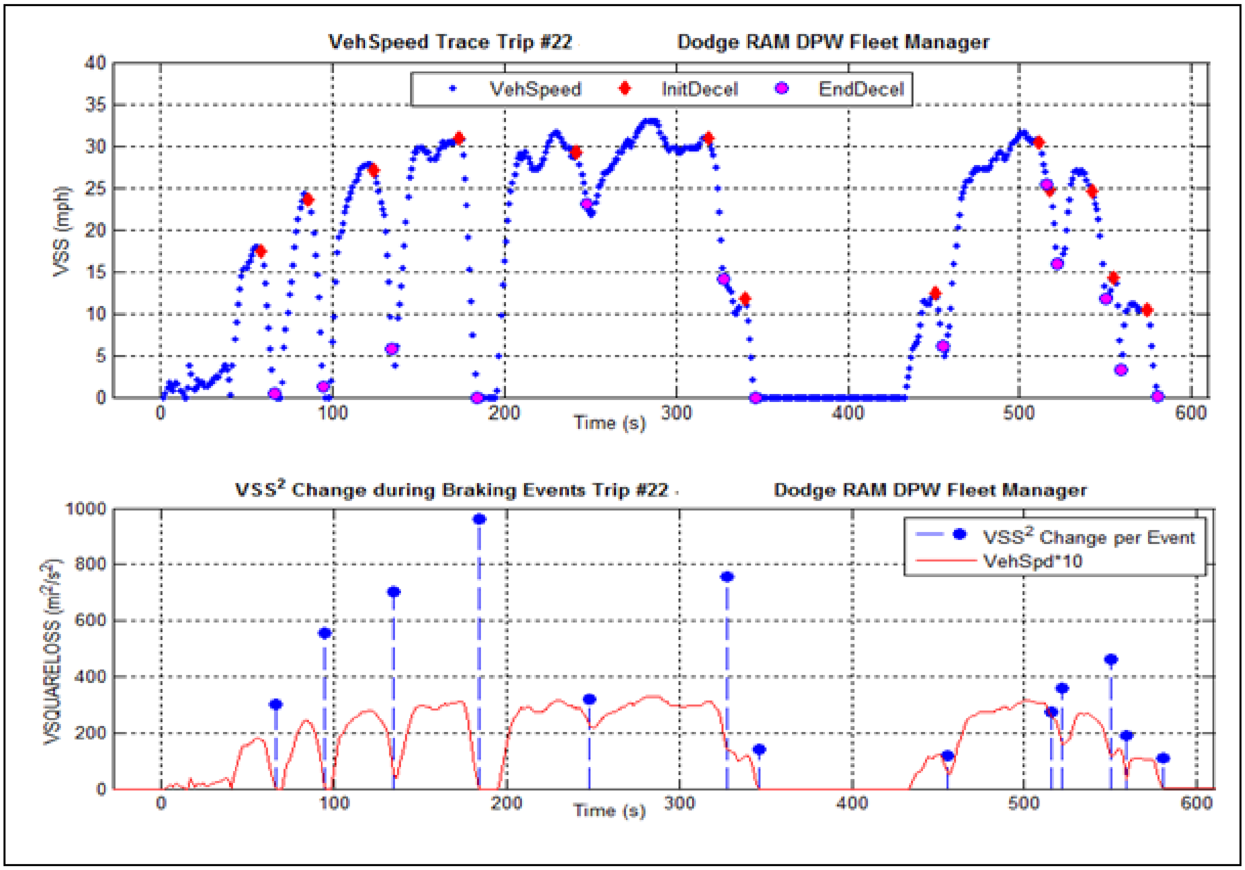


Figure 5: Braking events with corresponding change in Vehicle Speed Square between start and end of each event

To be able to compare energy recovery potential during braking between different driving cycles and/or vehicles, *VSquareLoss* is normalized by the distance (*Dist)* travelled over the same observation period and multiplied by the vehicle mass divided by 2 as follows:

VSL = VSquareLoss x VehMass/Dist/2

Another metric for evaluating potential regeneration benefits has been calculated as follows. A histogram of all the Braking Events during the vehicle's observation period has been constructed by binning events on *delVSS²*. This distribution is shown below in Figure 6. Notice the distribution is given in Counts, not Percentages. The superimposed pink trace shows the cumulative sum of the Event number normalized to 100%. The bin corresponding to either the 50% or 75% crossover can be used as a comparison metric. When vehicles of different mass are compared, the bin scale must be multiplied by the vehicle mass divided by 2, that is, it must be converted to the same energy bin axis.

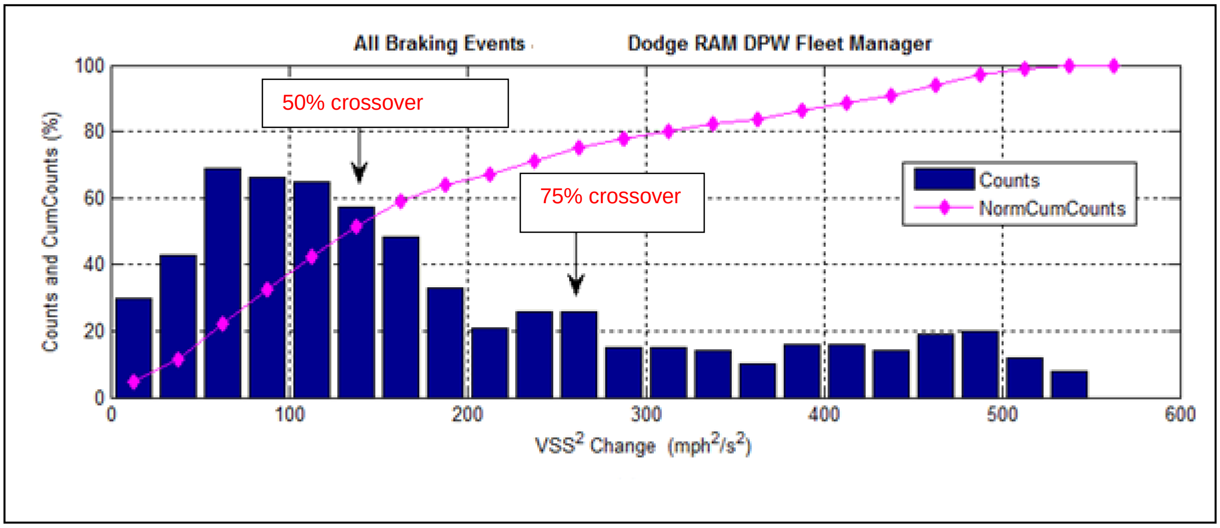


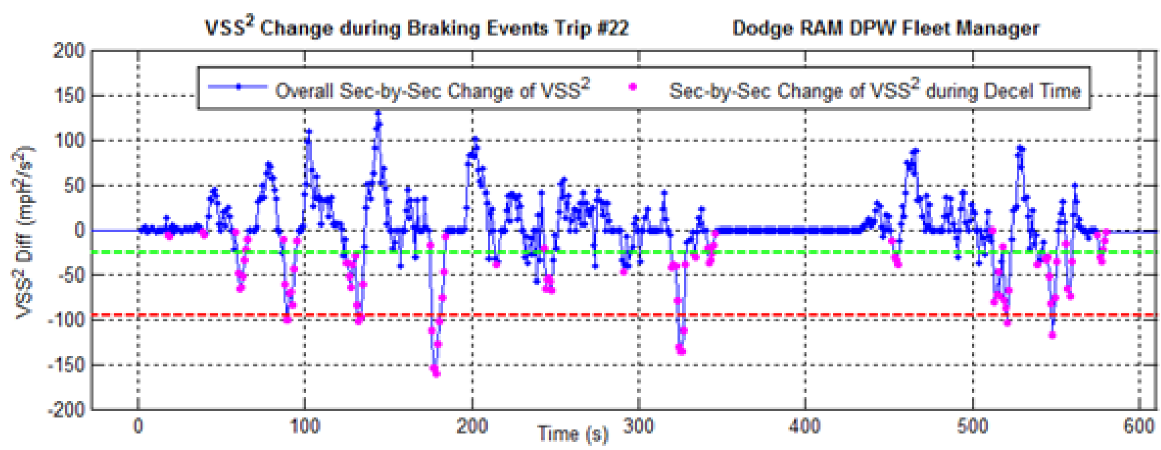
Figure 6: Distribution and cumulative count sum of the second-by-second changes in VSS² for all deceleration points

Additional Considerations Regarding Regeneration Power Limitations

VSquareLoss must be understood as an estimate of the upper limit of energy that can be potentially harvested during regeneration. In electric (EV) and hybrid electric vehicle (HEV) applications, friction braking is blended with the deceleration from regeneration to add braking action when the driver demand for deceleration rate exceeds the power absorption capability of the regenerative energy recovery system (for instance, at the beginning of a hard brake from high speeds and as the vehicle comes to rest). This action decreases the overall recovery efficiency.

However, the *VSquareLoss* calculation can be easily adapted to take into account the clipping of regenerative braking at high speeds due to the power absorption limitations of the regeneration system. Figure 7 below shows *VSS² Diff* which represents second-by-second changes in VSS² as a function of time. This can be translated to potential energy by factoring in the vehicle mass. The area delimited by the zero line and the dotted trace is the

same as *VSquareLoss* defined previously. The area can be clipped by a lower bound (red dashed line) corresponding to the maximum power that can be absorbed by the regeneration system. For instance, in Figure 6, a loss of 100 mph^2/sec^2 in 1 sec for a 6,000 lb vehicle is equivalent to approximately 28 kW of power, well below a typical 50 kW limit for a full EV battery pack. Similarly, the upper portion of the enclosed area of interest (low braking power region highlighted by the green dashed line and the zero line) can be excluded to reflect the reduced effect of regenerative braking.



Magenta dots indicate the points included in the braking event identification. The dashed lines illustrate the band outside which the function should be clipped to account for limitations in regenerative braking capabilities.

Figure 7: Second-by-second changes in VSS^2 (*VSS^2 Diff*) plotted as a function of time

The key point in Figure 7 is that the driving profile for vehicles operating inside Fort Carson shows relatively mild deceleration rates and low velocities, thus, the potential for regenerative energy recapture if these vehicles are electrified could be larger than in other conditions.

Appendix D: Detail on Contents of Graphical Summary Reports

The following table shows descriptions of each of the metrics in the Summary Report.

Table 5: Description of Items in Graphical Summary Report

List and short description of the items included in the Graphical Summary Report	
Global Parameters	**Description**
Total Mileage (mi)	Total distance traveled by the vehicle during the entire observation period.
Highest Daily Mileage (mi)	Greatest distance traveled in one day.
Observation Time (dd)	Number of day the logger was recording on the vehicle .
N. Days of Utilization	Number of days the vehicle moved.
UtilizationTime(hh:mm)	Total time the vehicle was being used (motion + idle time).
Time at Speed (hh:mm)	Total time the vehicle was moving.
% IdleTime	Percentage of usage time while the vehicle is idling.
Average Speed (mph)	Mean vehicle speed value over all speed data (1s data-rate).
%Time Speed>=40 mph	Percentage time the vehicle was moving at a speed >= 40 mph.
N. Total Starts	N. of engine start measured through the OBD logger. N. of trips for GPS logger.
% Accel Time	Percentage of the usage time the vehicle is accelerating above the threshold.
% Decel Time	Percentage of the usage time the vehicle is accelerating above the threshold.
% Cruise	Percentage of time the vehicle acceleration is within the threshold band.
Plots	**Description**
Top Geo Map	Track of the vehicle movements for the entire Observation Period.
Vehicle Speed Distribution	Histogram of the Vehicle Speed data derived from the 1s timeseries excluding all the values that are equal to zero.
Daily Mileage	The bars show the cumulative distance traveled for each day during the observation period
Daily Usage Time	The Bar Plot shows: (a) the time in minutes the vehicle was used for each day including idle time (green bar); (b) the time in minutes the vehicle is idling (yellow bar). For the OBD logger derived data, idle time is when the vehicle speed is zero since the logger records only when the engine is running. Idle time is not directly measured for the case of the GPS-only loggers. In this case it is extrapolated from the speed data assuming that every time the vehicle stops and resumes moving within 120 sec the engine had not been turned off. This assumption is based on the GPS observations.
Number of Daily Trips	The Bar Plot shows: (a) the number of engine starts measured with the OBD logger (magenta bar) since each engine starts defines a Trip even is the vehicle did not move; (b) the number of trips for each day during which the vehicle moved for more than 0.2 mi. For the case of the GPS logger, since the actual engine starts is not measured, the Trip is defined as a series of sequential vehicle motion segments chained together as long as the time in between motion segments is less than 120 sec.
Vehicle Speed	The plot shows the Vehicle Speed as a function of time. The time axis starts from 12 AM of the first day. The speed trace shows during which days the vehicle was moving. Refer to the Daily Geo Maps for the actual tracks.
Daily Geo Maps	Individual tracks for the Trips in each day are shown in separate plots. Individual trips are identified by color and the end location of a trip is shown by a corresponding colored diamond marker. For ease of following the vehicle movements, tracks for trips of less than a mile are not shown in the Geo Plots.
Refer to the analysis section of the report for more details on the derivation of each item.	

Additional explanation follows on how certain items in the Graphical Summary Report have been calculated and what they mean. Specifically:

1) The Observation Time includes the day the logger was installed and the day it was removed even if installation and/or removal occurred in the middle of the day. In both cases, a note is added at the bottom of the report.
2) The Utilization Time is the total number of hours and minutes the vehicle was being used, and includes the engine Idle Time. For the OBD loggers, Idle Time is derived from the OBD vehicle speed data summing all time intervals of zero speed with key on. For the GPS loggers, Idle Time was inferred based on the Trip segmentation criteria described in the Data Pre-processing section.
3) Time at Speed indicates the total time the vehicle was moving. This parameter is included since Idle Time is estimated in the GPS data case and calculated from measured quantities in the OBD case.
4) The Number of Starts, as above, is estimated for the GPS case while it is measured for the OBD case.
5) The Average Speed reported is the mean vehicle speed after excluding the zero speed data. This average value is always larger than the value calculated by rationing the Total Mileage by the Utilization Time. Notice that because of noise in the GPS data, the GPS derived vehicle speed is seldom zero. Thus, throughout this analysis, speed values < 0.5 mph are taken as zero. This parallels the way vehicle speed is calculated on-board.
6) The percentage of time the vehicle speed is above 40 mph is also calculated excluding zero speed data. This threshold value was suggested because of electrification considerations.
7) The Acceleration, Deceleration and Cruise time are calculated from differences between two consecutive vehicle speed data and applying a two-point average filter. A threshold value of 0.08 mph/s was used to separate cruise periods from acceleration and deceleration conditions. This value was chosen in conjunction with the development of a parameter related to estimation of recoverable kinetic energy during braking and qualitatively supported by OBD Pedal Position data indicating that deceleration rates greater than this threshold correspond to Tip-out conditions.
8) The vehicle speed histogram is computed on the basis of equal speed bins of 2.5 mph. The bars in the graph are centered on the middle value of each bin.
9) The Daily Mileage and Usage Time plots show corresponding values computed for each day. If a Trip occurs across midnight, its Total Time is assigned to the day when the trip started. The same is done for reporting Daily Usage Time.
10) Many short trips of 0.1 to 0.2 miles have been observed in several driving profiles for the Fort Carson vehicles. The Daily Trips Number is reported as both the Total Number and the Number of Trips with measured displacement greater than 0.2 miles.
11) The Vehicle Speed trace is plotted as a function of time referenced to 12:00 AM of the first day the logger was installed. This trace provides visual information on whether the vehicle is used mainly during diurnal working hours or throughout the

entire day. This plot and the other bar plots also show whether there are days in which the vehicle is not used.

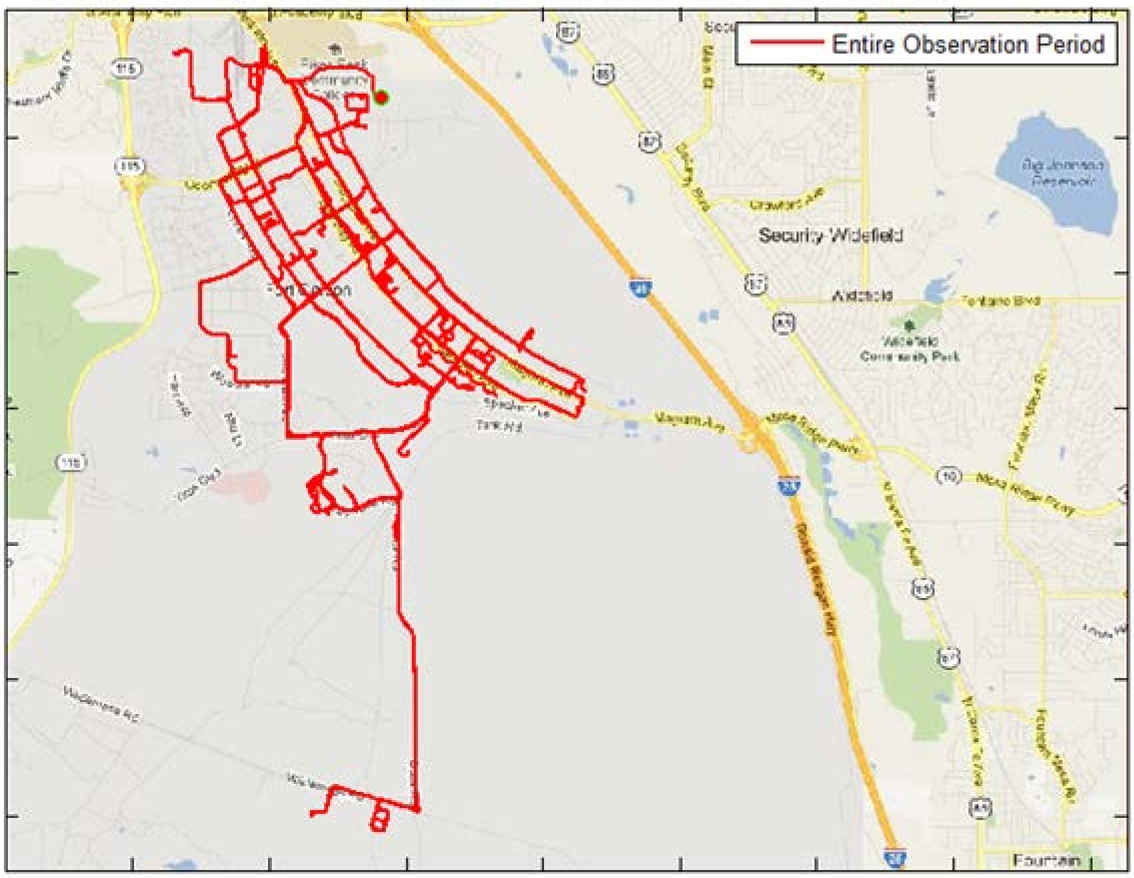
12) The Geo Map for the entire Observation Period was generated in MATLAB by overlaying the Latitude as a function of Longitude scatter plot over a map imported from Google Map after converting the degree values to miles at the Fort Carson base latitude. The Geo Map provides an indication of the geographical area of operation for the vehicle. Additional daily Geo Maps are provided separately for selective vehicles in Appendix E.

Appendix E: Daily Geo Map Plots

The geo map plots on the following pages show individual trips by day for three representative vehicles monitored at Fort Carson. Also included are summary tables for trip duration and distance plus a time line for each day showing when trips occurred during the day. Individual trips greater than one mile in distance are represented by unique color traces on the daily plots.

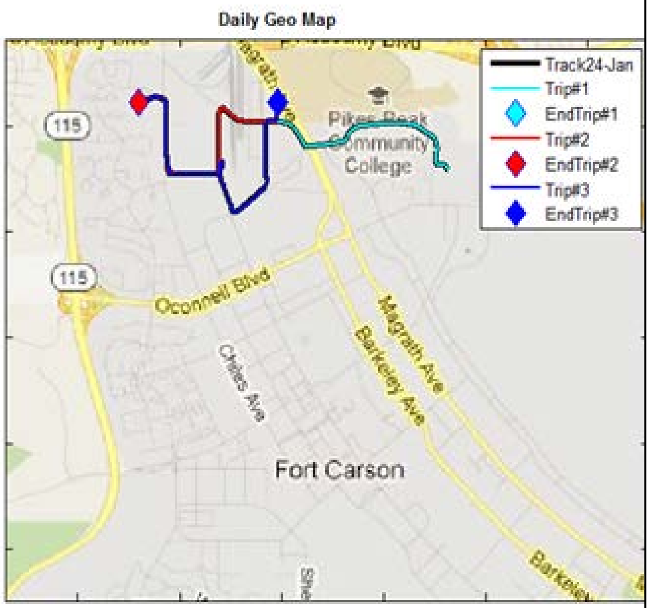
The first vehicle is a 2011 Ford F-250 Super Duty work truck. The first plot below shows the combined daily tracks from the entire two-week observation period, 24 January to 7 February 2012. Individual day trip detail is shown on the following pages.

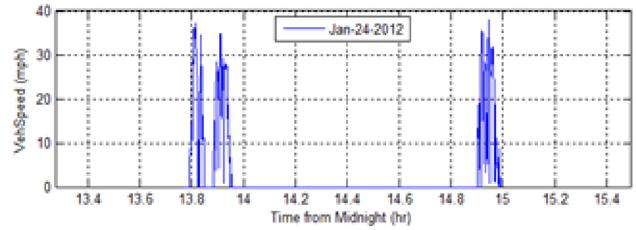
Geo Maps All Days - Jan 24 to Feb 7, 2012 - Work Truck - F250-Super Duty 2011



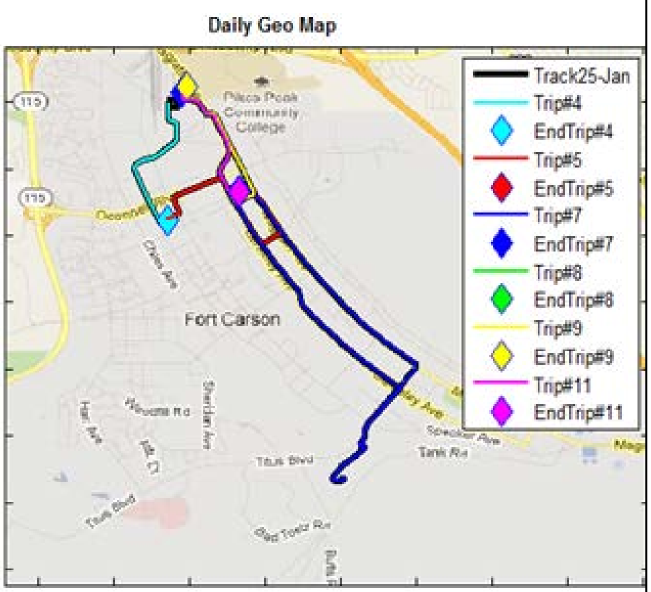
Daily Geo Maps (Trips >1mi)

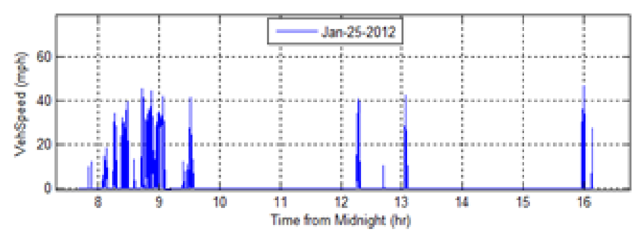
24 – 25 Jan 2012





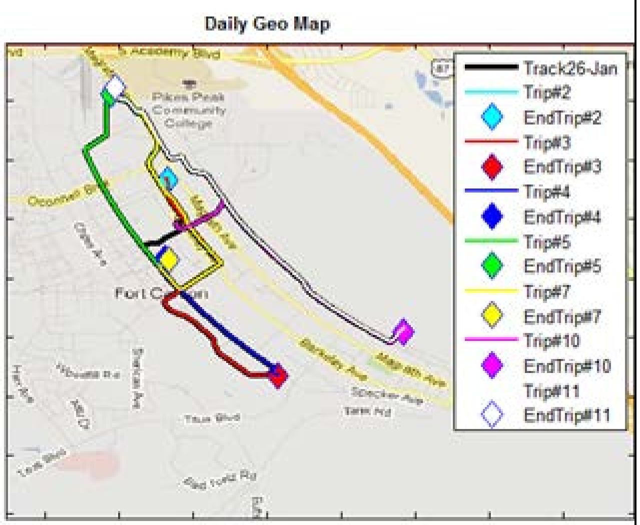
24-Jan-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	268	1.1
2	254	1.3
3	319	1.5

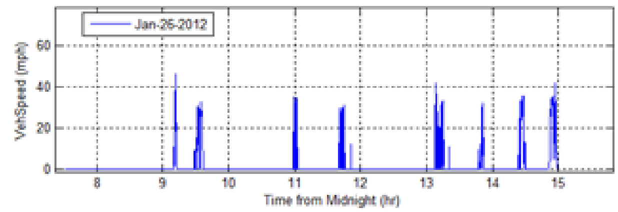




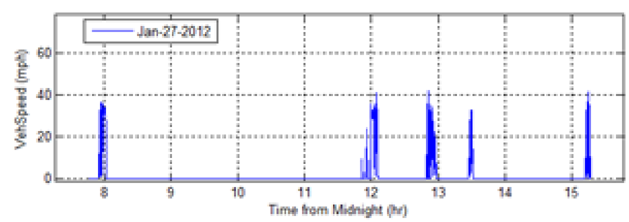
25-Jan-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	541	0.1
2	56	0.1
3	793	0.5
4	231	1.0
5	504	2.4
6	38	0.1
7	1418	6.9
8	1012	1.2
9	229	1.1
10	39	0.1
11	232	1.0

Daily Geo Maps (Trips >1mi) | **26 – 27 Jan 2012**



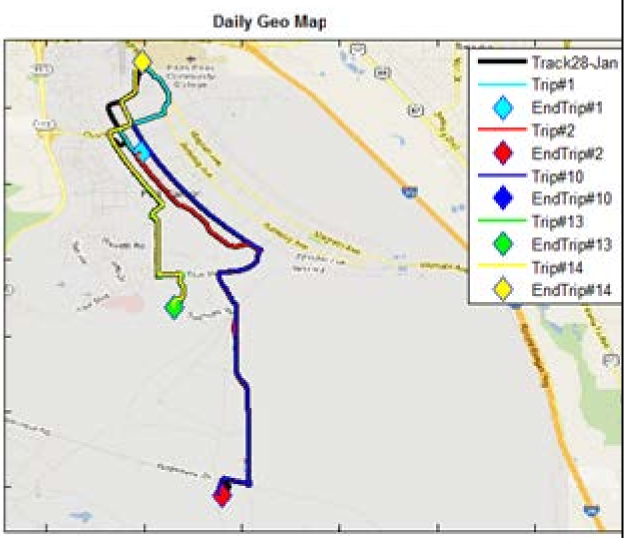


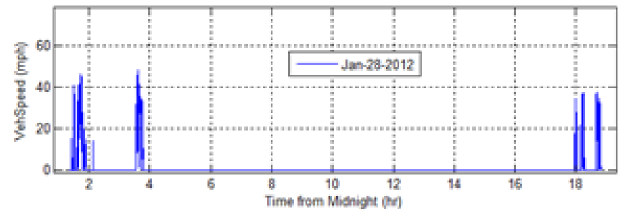
26-Jan-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	356	0.0
2	291	1.1
3	457	2.2
4	309	1.3
5	333	1.6
6	45	0.1
7	732	2.2
8	11	0.0
9	297	0.6
10	387	2.1
11	530	2.9



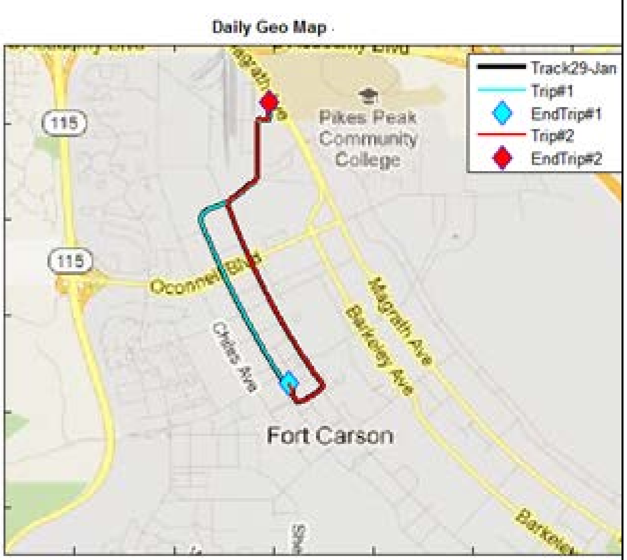
27-Jan-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	959	2.9
2	877	3.1
3	538	2.8
4	232	1.0
5	295	1.7

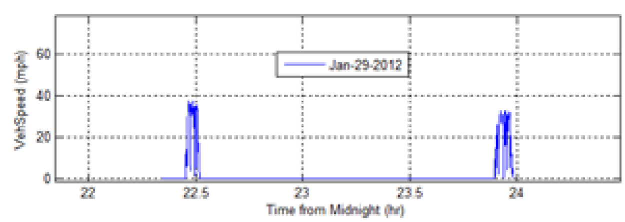
Daily Geo Maps (Trips >1mi)	**28 – 29 Jan 2012**





28-Jan-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	621	1.7
2	663	5.5
3	58	0.2
4	240	0.5
5	550	0.2
6	222	0.0
7	116	0.0
8	307	0.0
9	324	0.0
10	801	6.5
11	245	0.9
12	18	0.1
13	410	2.5
14	626	3.7

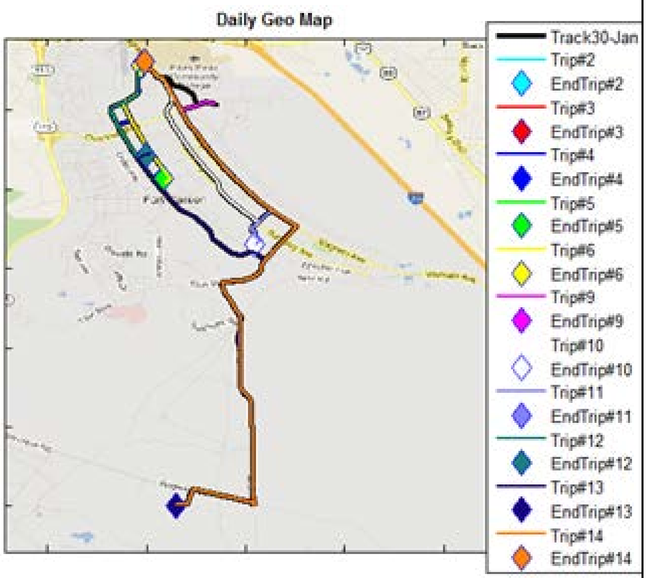


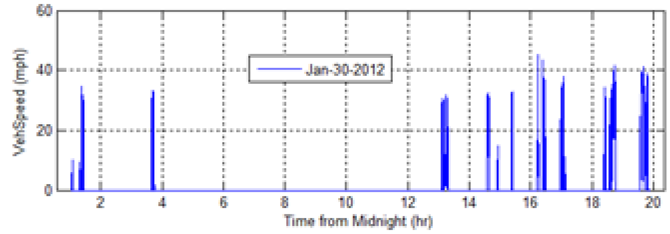


29-Jan-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	634	1.7
2	314	1.8

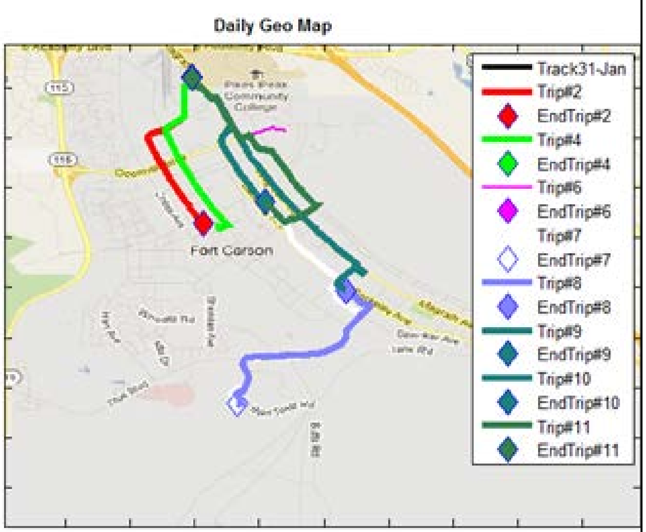
Daily Geo Maps (Trips >1mi)

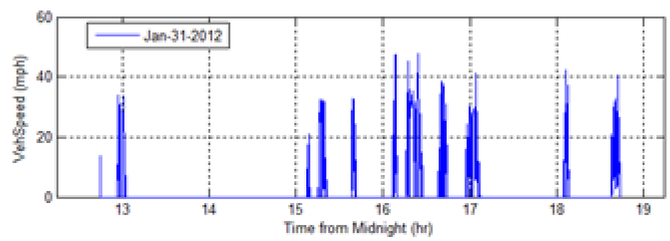
30 – 31 Jan 2012





30-Jan-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	48	0.1
2	496	2.0
3	304	1.7
4	349	1.8
5	331	1.8
6	251	1.6
7	46	0.1
8	244	1.0
9	216	1.1
10	386	2.6
11	636	2.6
12	276	1.4
13	856	5.9
14	1005	6.9

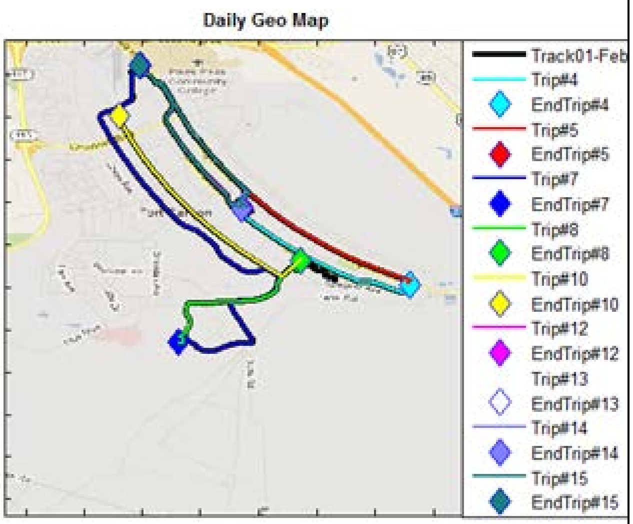


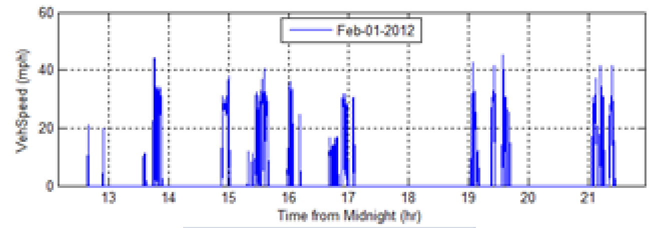


31-Jan-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	27	0.1
2	387	1.6
3	140	0.0
4	349	1.7
5	269	1.0
6	220	1.1
7	681	4.2
8	400	1.8
9	714	2.6
10	406	1.4
11	464	2.1

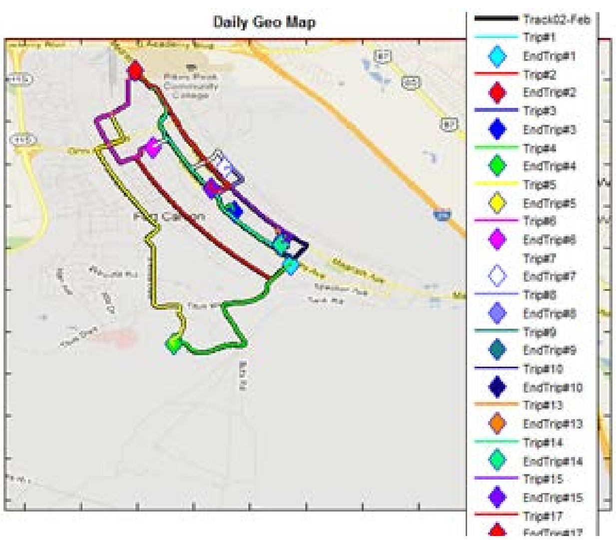
Daily Geo Maps (Trips >1mi)

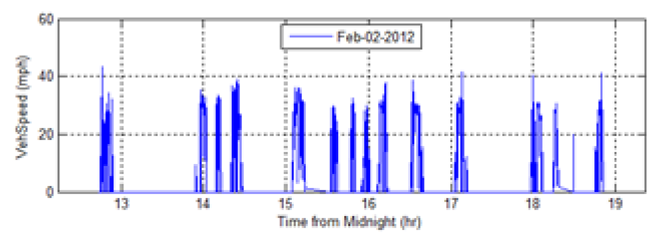
1 – 2 Feb 2012





1-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	63	0.2
2	74	0.2
3	208	0.2
4	561	3.5
5	507	3.3
6	32	0.1
7	1003	4.9
8	1508	1.8
9	566	0.8
10	507	2.4
11	149	0.7
12	480	2.1
13	300	1.9
14	510	2.3
15	1382	5.7

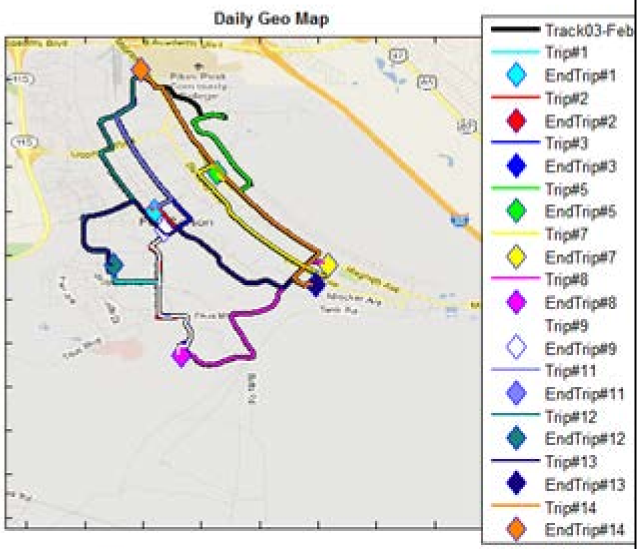


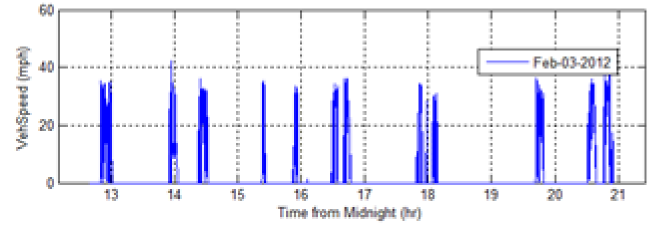


2-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	640	2.6
2	479	2.3
3	233	1.2
4	507	3.0
5	619	3.7
6	389	1.6
7	517	1.1
8	472	1.3
9	433	2.4
10	590	3.2
11	24	0.0
12	104	0.0
13	580	2.4
14	594	2.4
15	248	1.1
16	30	0.1
17	389	1.8

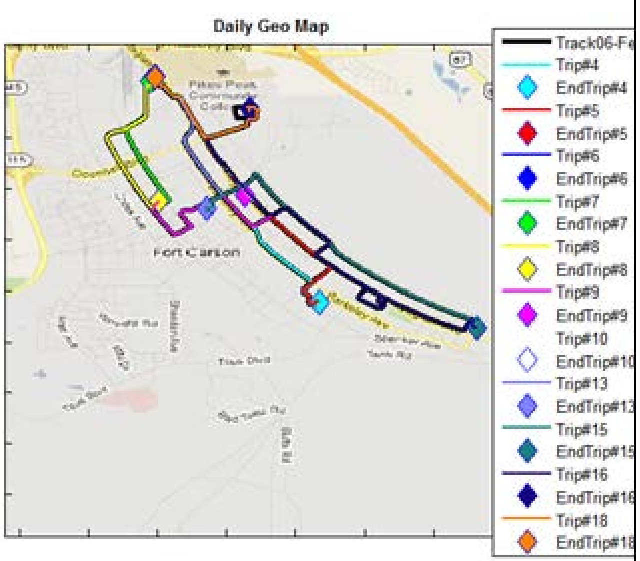
Daily Geo Maps (Trips >1mi)

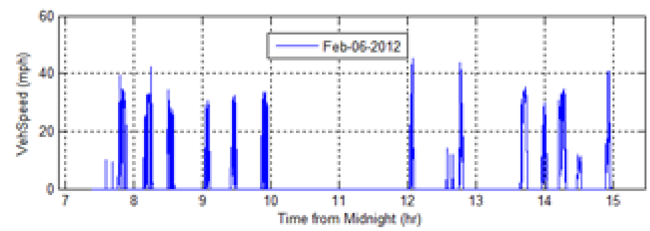
3 & 6 Feb 2012





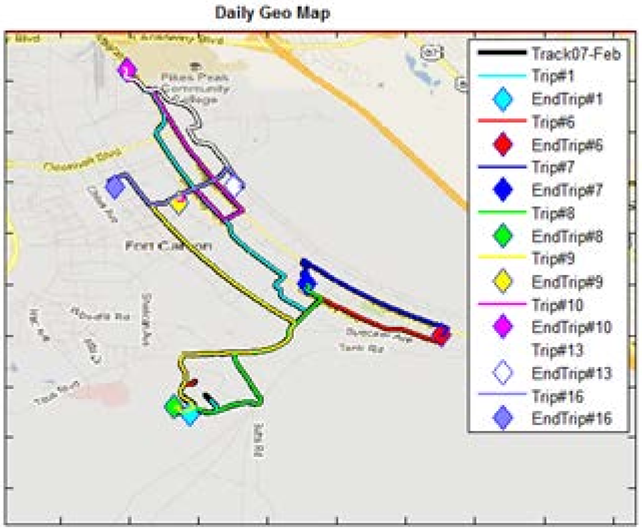
3-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	1354	4.2
2	673	2.2
3	610	3.7
4	196	1.0
5	345	1.5
6	1068	0.0
7	386	2.1
8	399	2.4
9	353	1.7
10	76	0.3
11	331	1.8
12	495	2.8
13	487	3.1
14	552	3.1

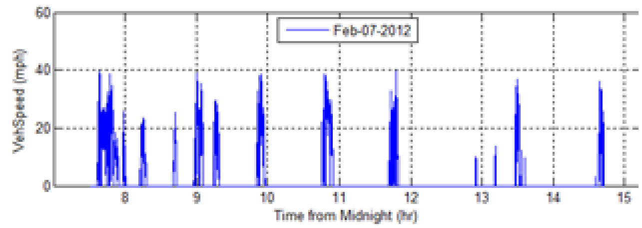




6-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	538	0.0
2	95	0.0
3	38	0.0
4	712	2.6
5	482	2.7
6	393	1.6
7	301	1.4
8	385	1.4
9	349	1.7
10	219	1.5
11	227	0.2
12	32	0.1
13	758	1.5
14	393	0.0
15	637	2.6
16	1376	4.0
17	609	0.5
18	343	1.3

Daily Geo Maps (Trips >1mi)	**7 Feb 2012**

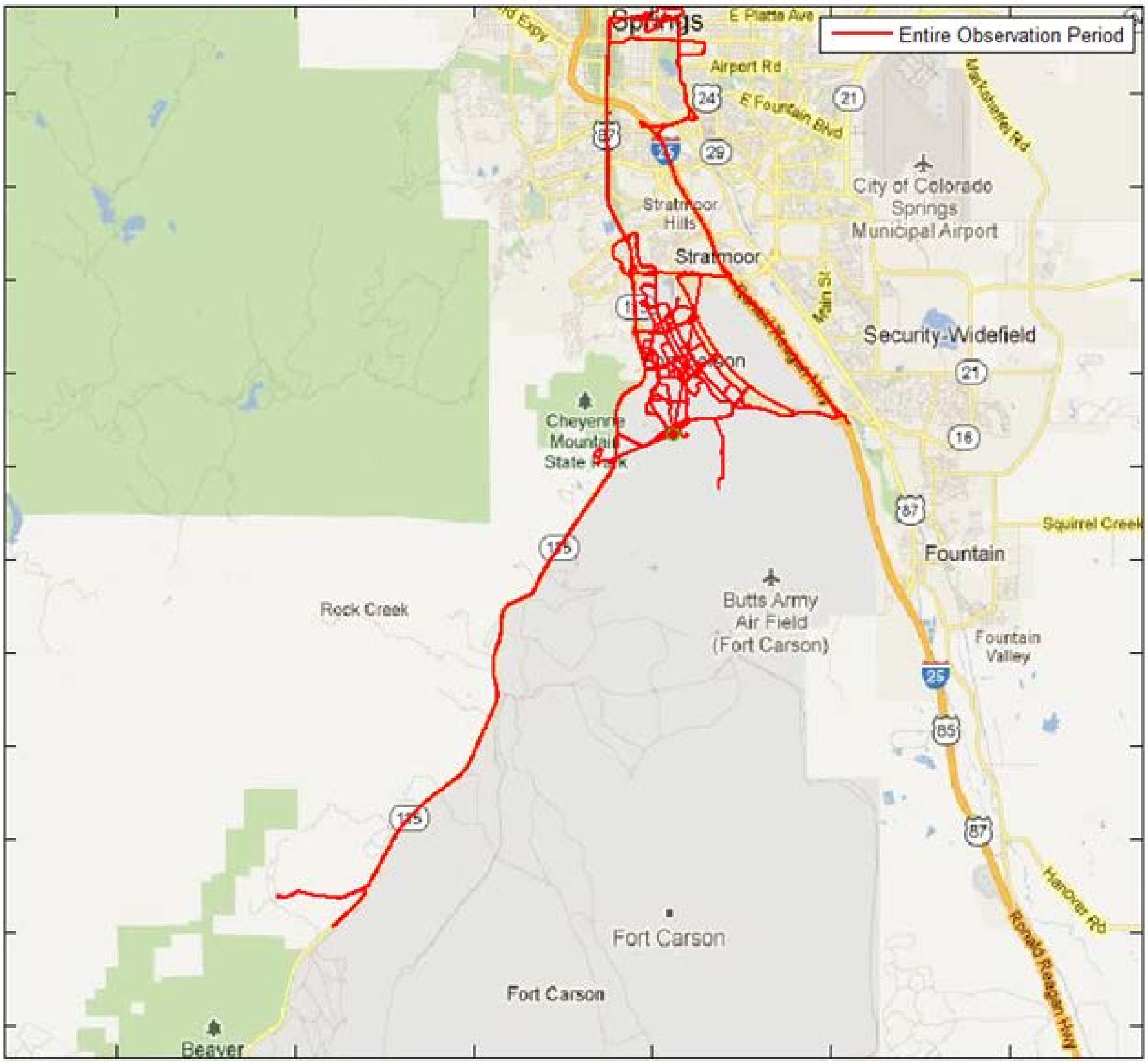




7-Feb-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	1496	4.9
2	143	0.4
3	1734	1.0
4	186	0.0
5	302	0.6
6	502	2.5
7	405	1.5
8	404	2.1
9	804	3.3
10	552	2.2
11	167	0.1
12	36	0.1
13	362	1.6
14	10	0.0
15	4	0.0
16	326	1.4

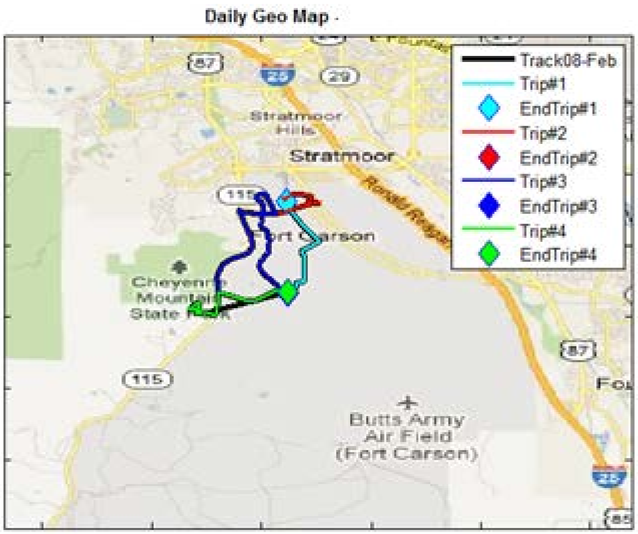
The next vehicle is a 2004 Ford E-350 Ambulance that was monitored from 8 - 22 February 2012. The first plot below shows the combined daily tracks from the entire two-week observation period and individual day trip detail is shown on the following pages.

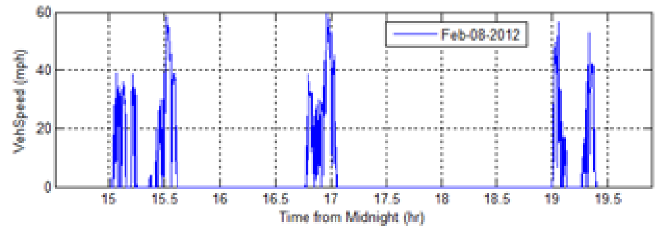
Geo Maps All Days - Feb 8 to Feb 22, 2012 - Ambulance - Ford E-350



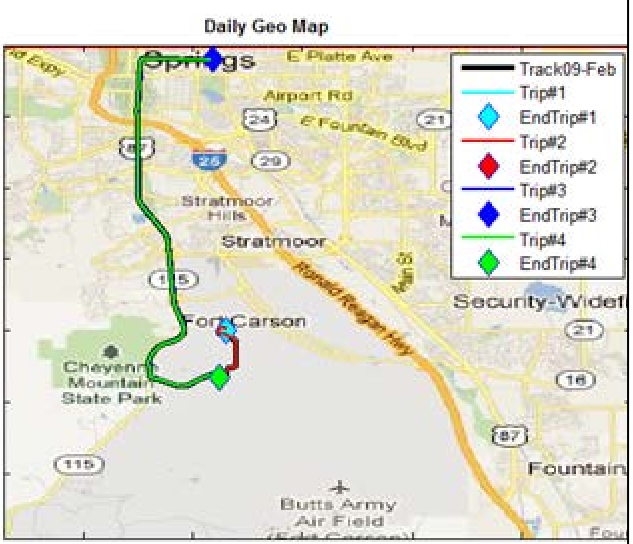
Daily Geo Maps (Trips >1mi)

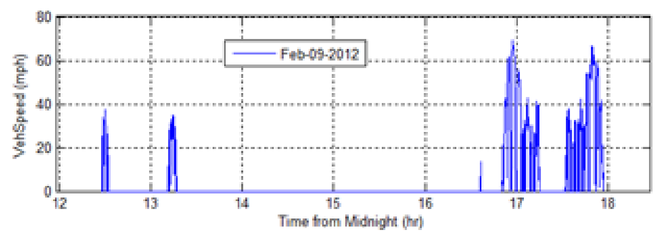
8 – 9 Feb 2012





8-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	500	2.8
2	1534	6.3
3	1048	8.0
4	1422	5.5

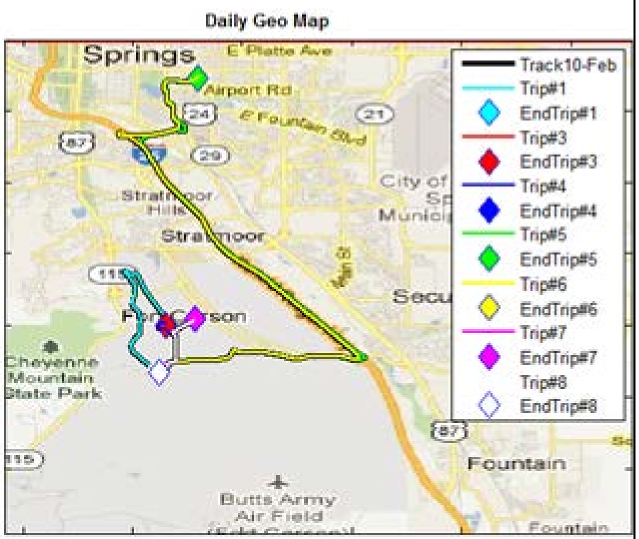


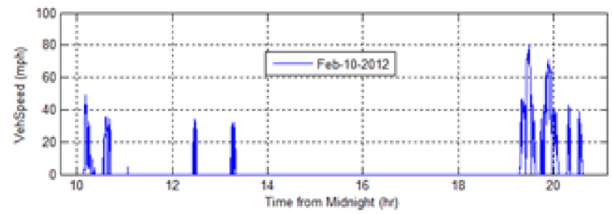


9-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	289	1.5
2	421	1.9
3	2401	11.3
4	1572	11.2

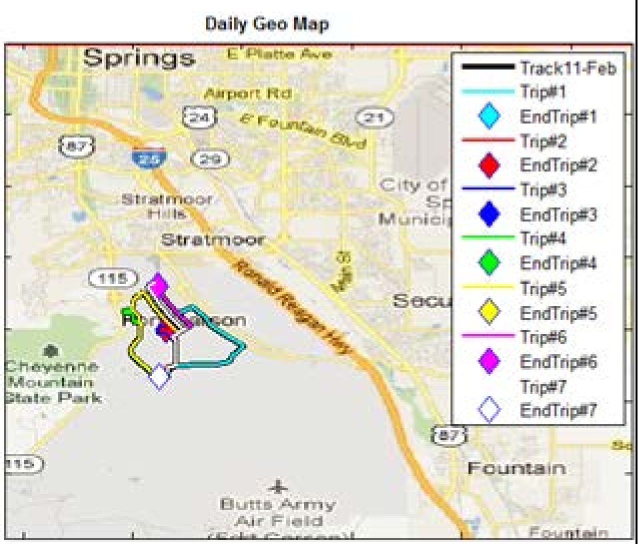
Daily Geo Maps (Trips >1mi)

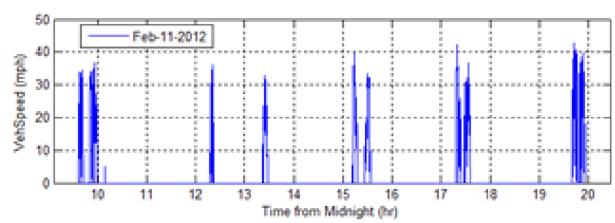
10 – 11 Feb 2012





10-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	2053	6.4
2	58	0.0
3	334	1.5
4	408	1.9
5	1242	13.5
6	1443	14.0
7	323	1.8
8	382	1.9

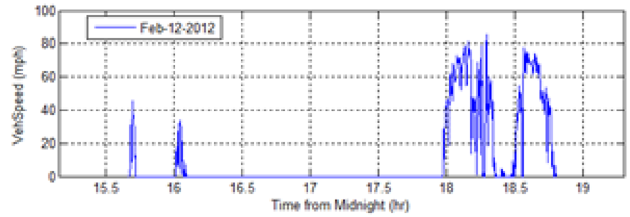




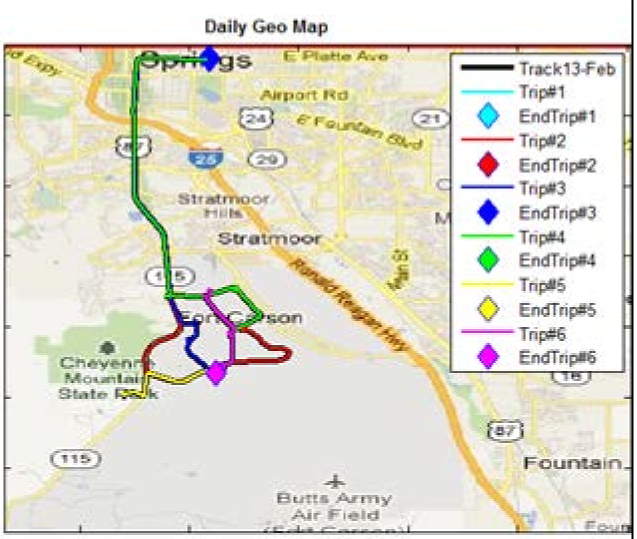
11-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	2001	5.7
2	304	1.5
3	435	1.9
4	1363	4.4
5	1151	5.2
6	373	2.9
7	495	3.1

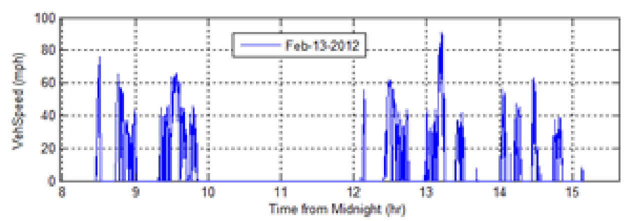
Daily Geo Maps (Trips >1mi)

12 – 13 Feb 2012



12-Feb-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	1535	2.0
2	3000	33.2

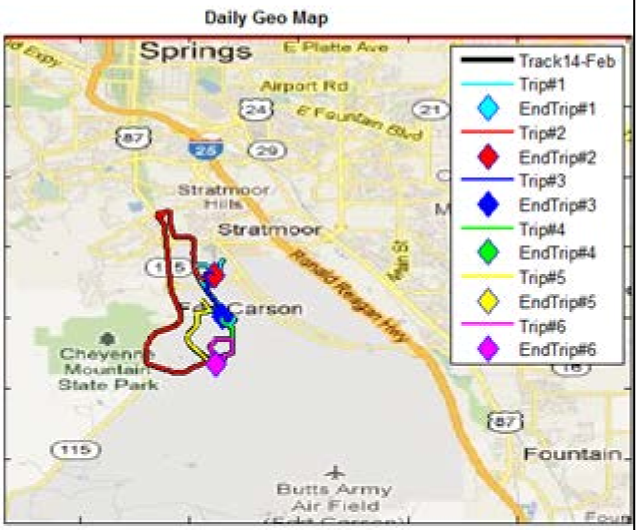


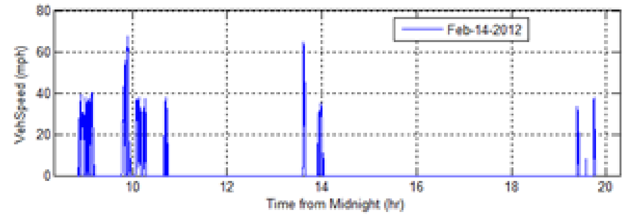


13-Feb-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	2019	11.2
2	1941	15.4
3	2433	10.4
4	2604	11.9
5	1066	4.9
6	2559	5.5

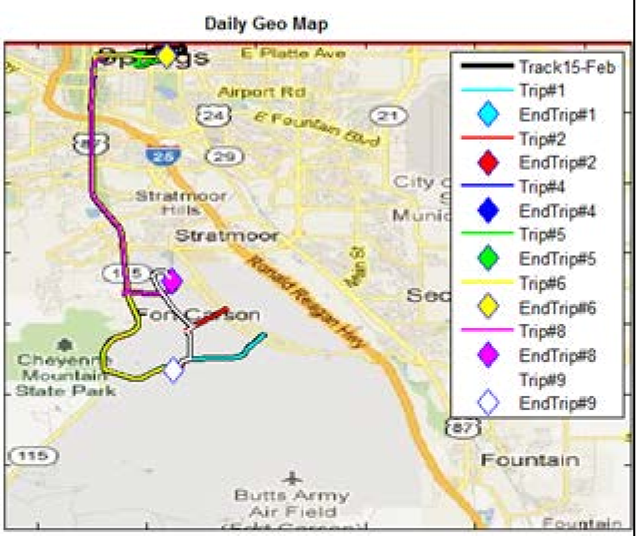
Daily Geo Maps (Trips >1mi)

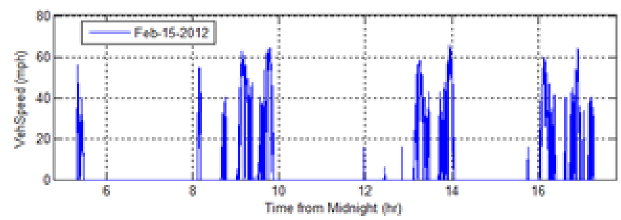
14 – 15 Feb 2012





14-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	1250	7.3
2	1521	8.5
3	269	1.6
4	317	1.6
5	1613	4.2
6	1487	2.2

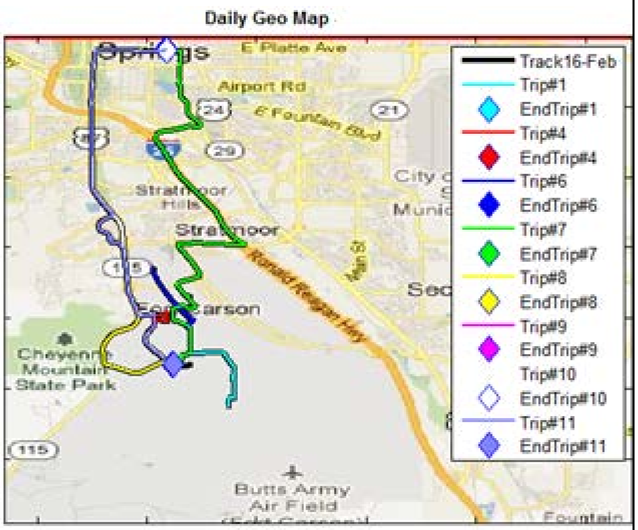


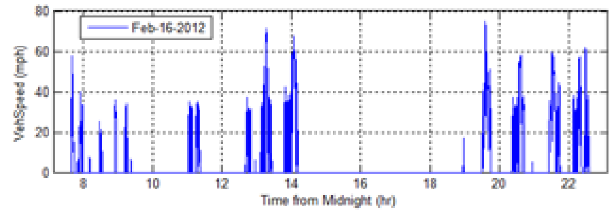


15-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	695	4.2
2	6369	26.8
3	1802	0.2
4	2380	11.3
5	1354	11.2
6	2358	11.3
7	227	1.1
8	957	7.6
9	969	3.6

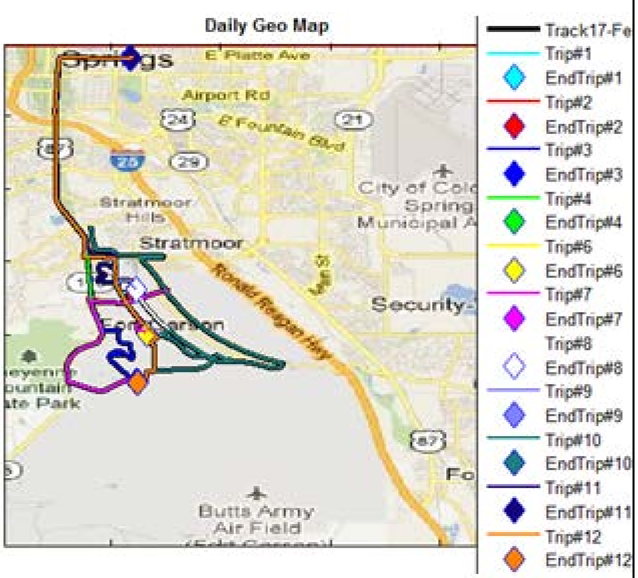
Daily Geo Maps (Trips >1mi)

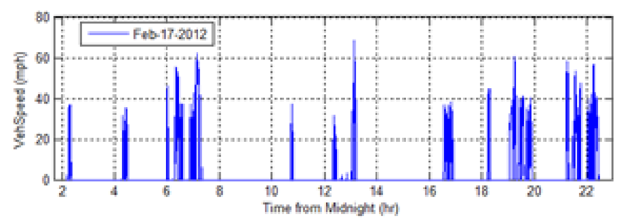
16 – 17 Feb 2012





16-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	1361	5.3
2	40	0.0
3	354	0.9
4	1388	3.6
5	67	0.0
6	1313	5.9
7	2757	12.2
8	1408	11.2
9	2904	10.3
10	5250	20.3
11	1778	10.6

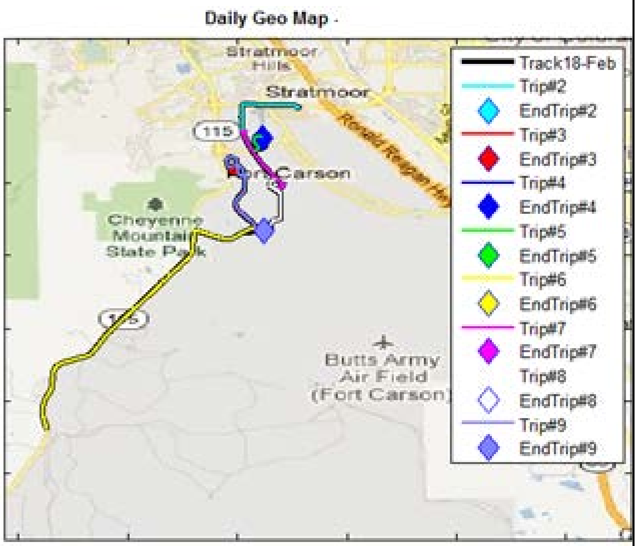


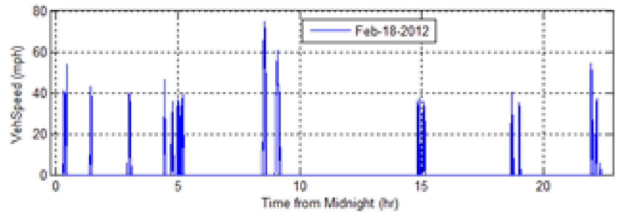


17-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	7765	3.7
2	537	3.1
3	2306	11.4
4	1529	11.2
5	47	0.0
6	344	1.6
7	3274	7.1
8	443	2.9
9	860	3.5
10	6150	21.4
11	2072	11.2
12	1577	10.5

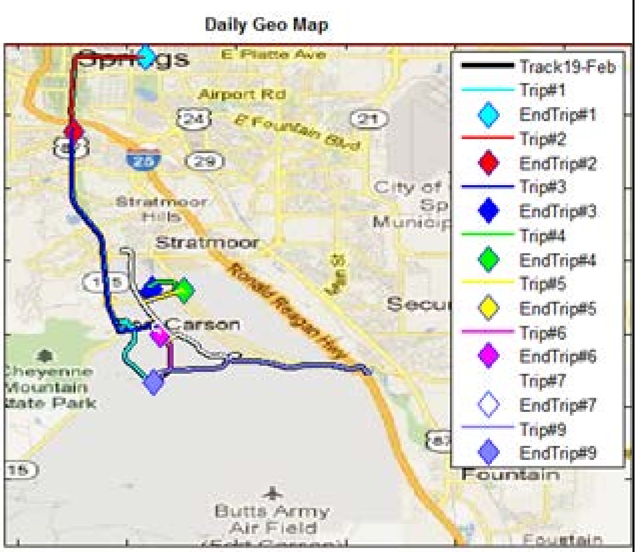
Daily Geo Maps (Trips >1mi)

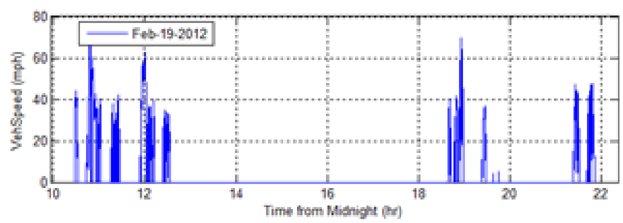
18 – 19 Feb 2012





18-Feb-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	3322	4.6
2	6136	4.8
3	1429	4.0
4	506	2.9
5	480	3.1
6	2650	14.7
7	1315	5.9
8	1435	3.2
9	1527	4.7

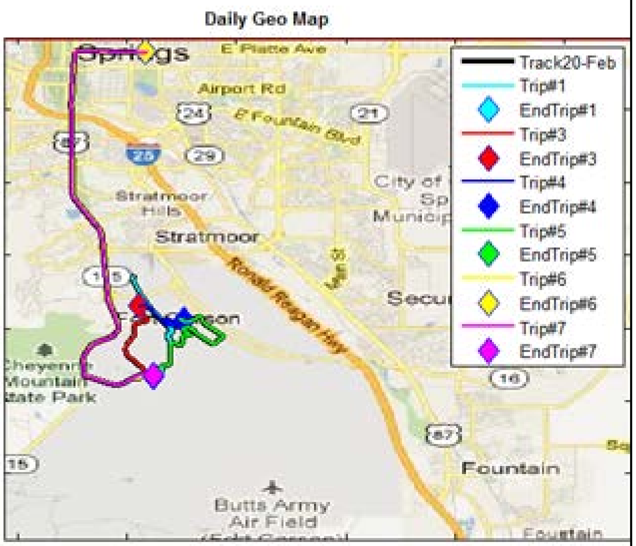


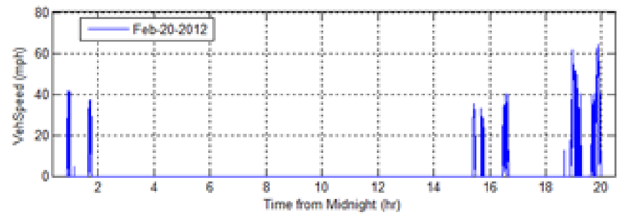


19-Feb-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	2103	11.0
2	700	3.2
3	994	7.4
4	188	1.0
5	628	3.3
6	252	1.5
7	2580	8.5
8	459	0.0
9	1741	8.4

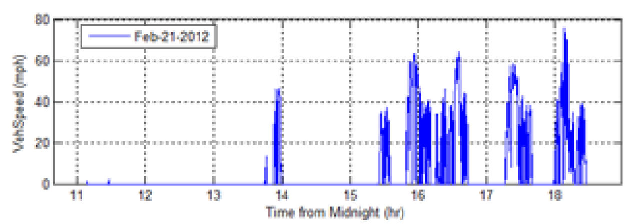
Daily Geo Maps (Trips >1mi)

20 – 21 Feb 2012



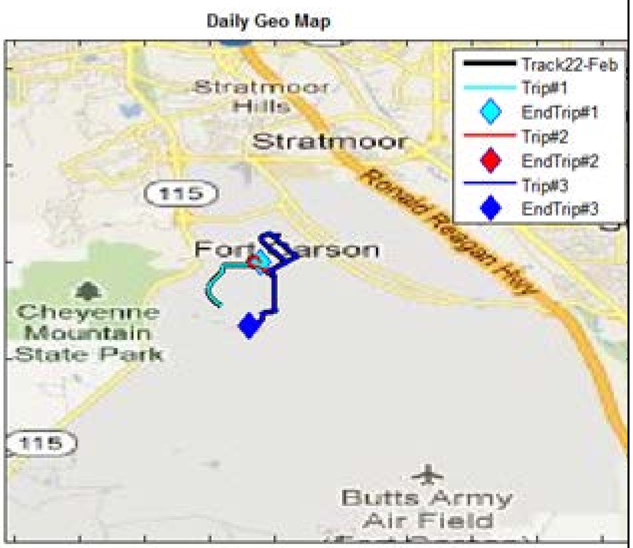


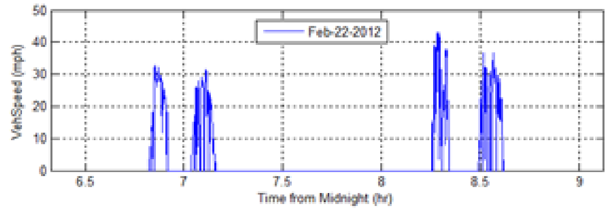
20-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	3230	6.0
2	19	0.0
3	435	2.2
4	455	1.7
5	829	4.1
6	2223	11.3
7	1384	11.2
8	1145	0.0



21-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	1145	0.0
2	837	3.1
3	8089	37.5
4	1057	8.8
5	517	3.1

Daily Geo Maps (Trips >1mi)	22 Feb 2012

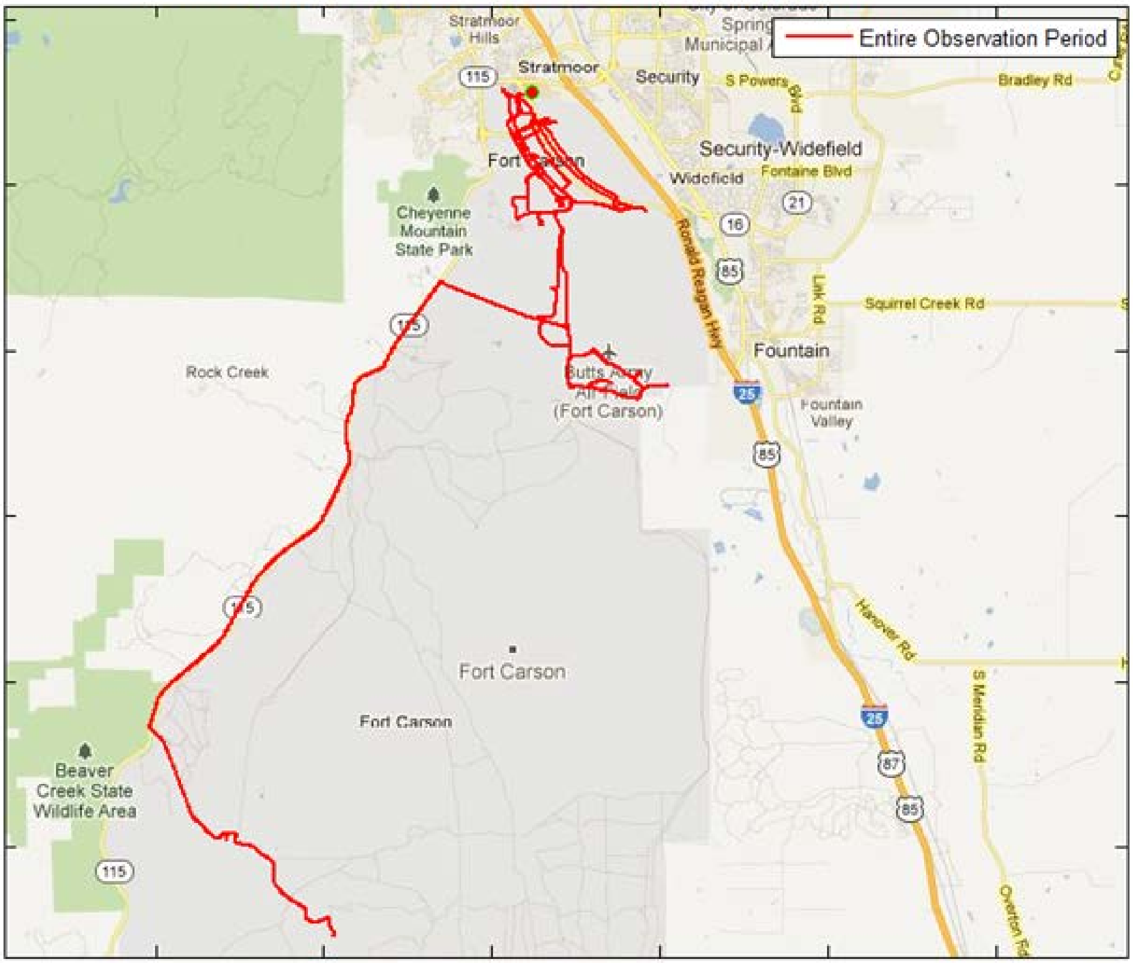




22-Feb-12		
TripN (#)	Duration (sec)	Distance (mi)
1	343	1.9
2	487	1.9
3	1365	4.5

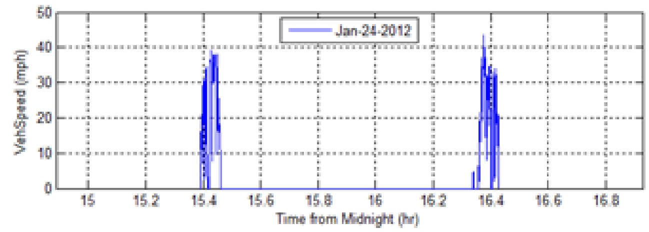
The third vehicle is a 2006 Dodge Dakota work truck that was monitored from 24 January to 7 February 2012. The first plot below shows the combined daily tracks from the entire two-week observation period and individual day trip detail is shown on the following pages.

Geo Maps All Days - 24 Jan to 7 Feb 2012 - Work Truck - Dodge Dakota

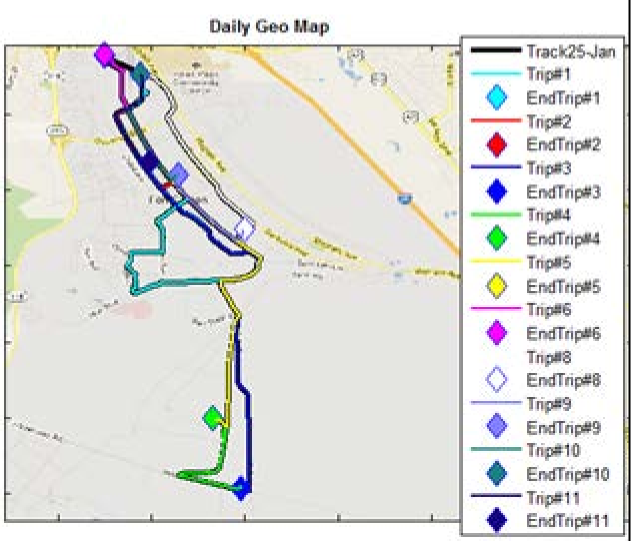


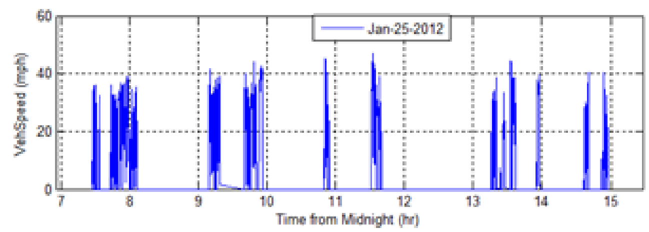
Daily Geo Maps (Trips >1mi)

24 – 25 Jan 2012



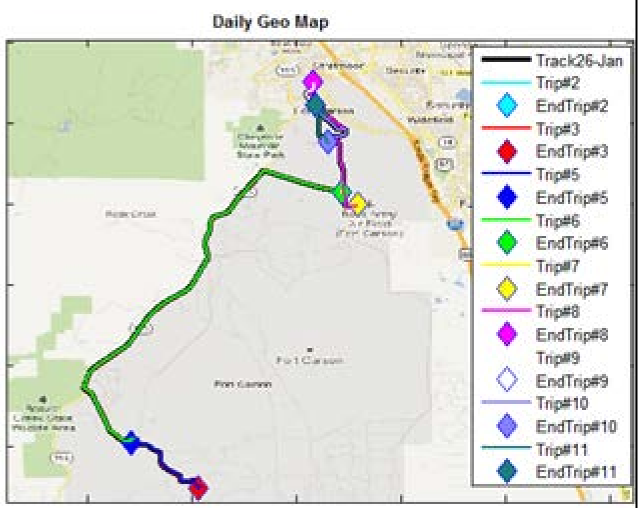
24-Jan-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	260	1.6
2	260	1.6

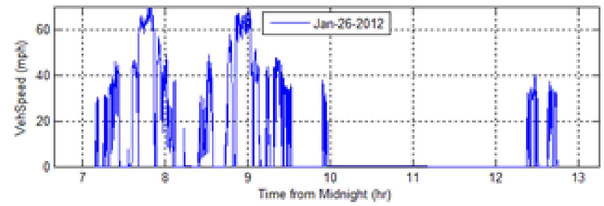




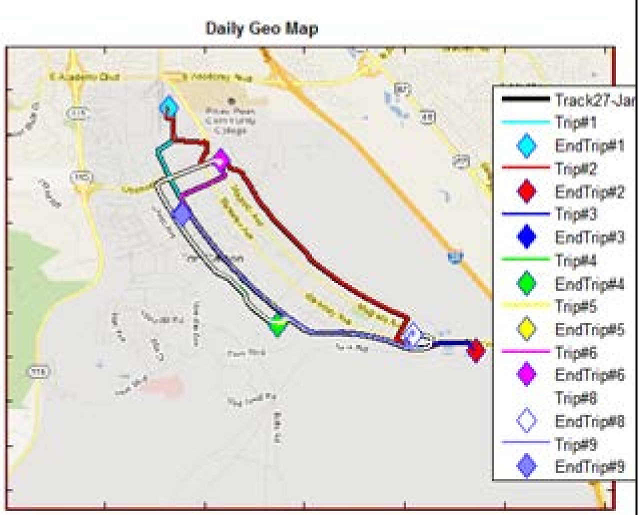
25-Jan-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	2445	9.1
2	592	3.8
3	996	6.5
4	296	1.9
5	582	4.2
6	297	1.6
7	242	0.6
8	317	2.3
9	181	1.2
10	276	1.5
11	375	1.4

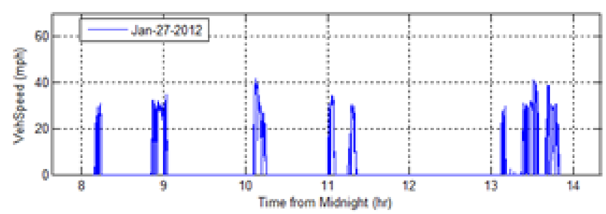
Daily Geo Maps (Trips >1mi)	**26 – 27 Jan 2012**





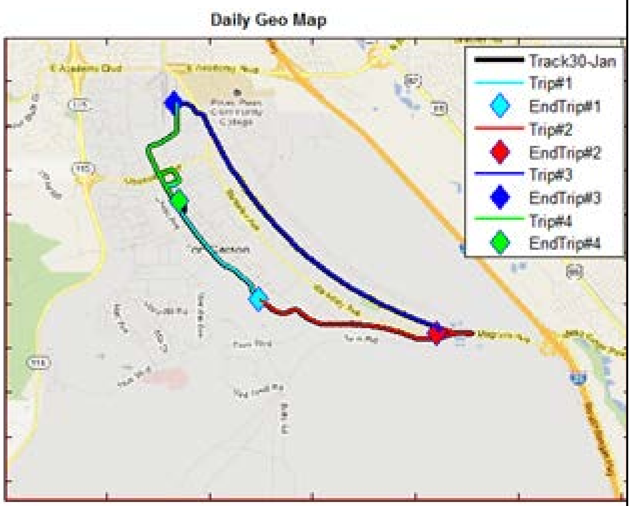
26-Jan-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	151	0.6
2	730	5.3
3	2044	22.2
4	54	0.1
5	700	4.1
6	1550	18.5
7	153	1.2
8	821	7.0
9	232	1.4
10	500	3.1
11	450	2.4

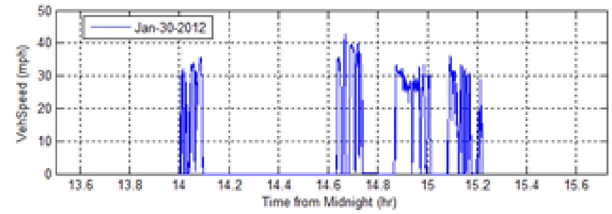




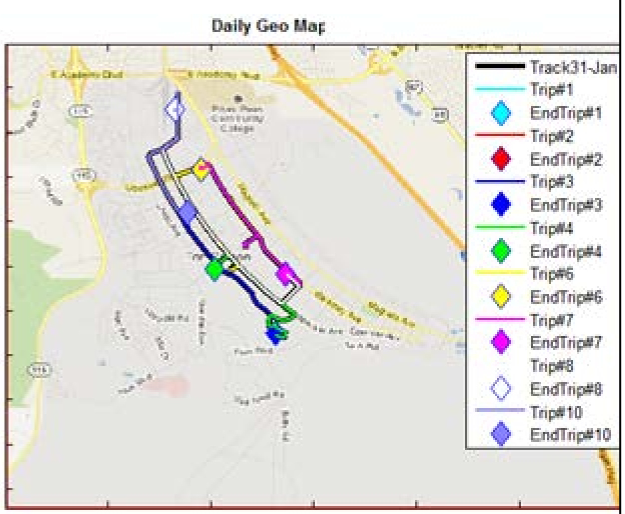
27-Jan-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	355	1.4
2	754	4.6
3	625	3.7
4	291	1.7
5	372	1.7
6	237	1.0
7	222	0.0
8	799	4.3
9	656	3.3

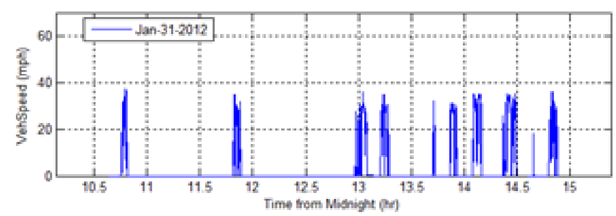
Daily Geo Maps (Trips >1mi)	**30 – 31 Jan 2012**





30-Jan-12		
TripN (#)	Duration (sec)	Distance (mi)
1	343	2.0
2	387	2.4
3	542	3.5
4	352	1.8
5	87	0.3

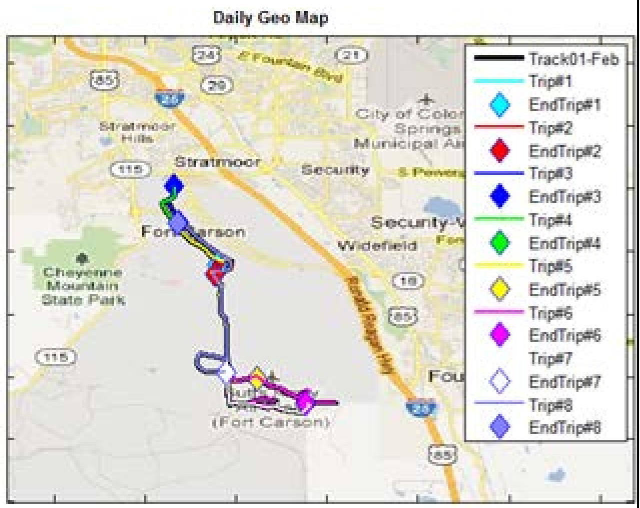


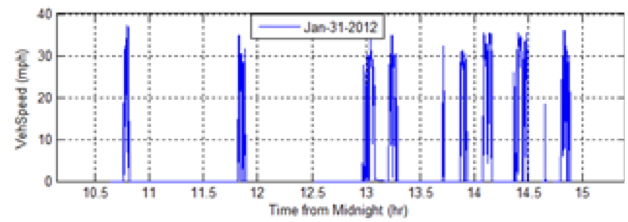


31-Jan-12		
TripN (#)	Duration (sec)	Distance (mi)
1	626	1.3
2	266	1.4
3	406	1.9
4	315	1.7
5	180	0.3
6	258	1.5
7	317	2.2
8	460	2.8
9	30	0.1
10	397	1.8

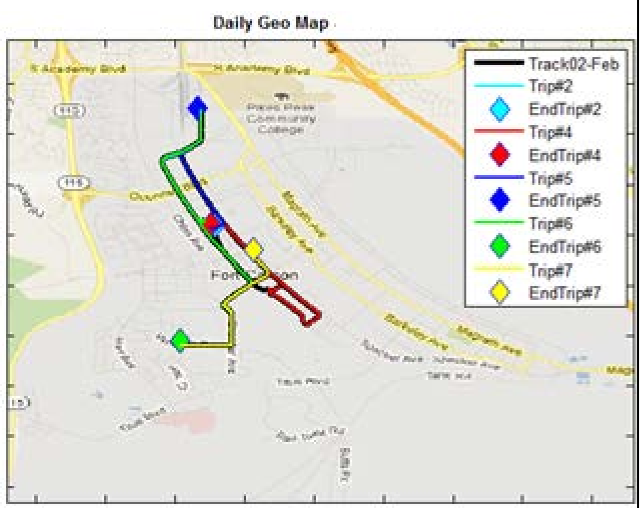
Daily Geo Maps (Trips >1mi)

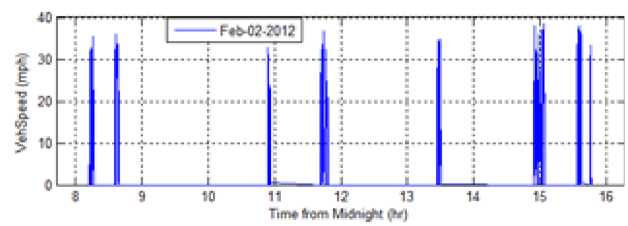
1 – 2 Feb 2012





1-Feb-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	485	2.8
2	272	1.4
3	957	3.4
4	244	1.4
5	785	6.2
6	2761	8.9
7	523	2.9
8	969	6.7

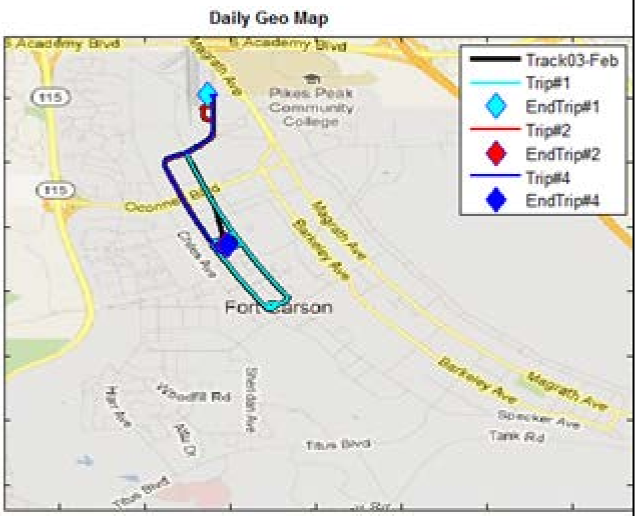


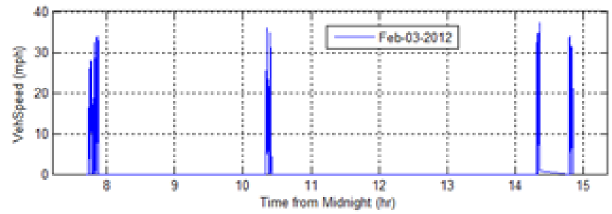


2-Feb-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	248	1.3
2	251	1.5
3	197	0.7
4	414	1.9
5	229	1.4
6	702	3.0
7	236	1.4
8	98	0.4

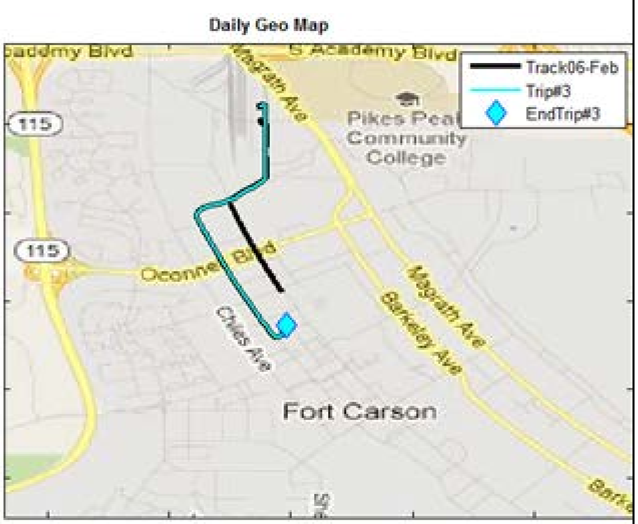
Daily Geo Maps (Trips >1mi)

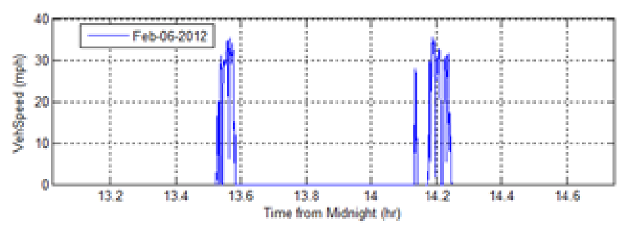
3 & 6 Feb 2012





3-Feb-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	674	2.8
2	318	1.5
3	201	1.0
4	227	1.4

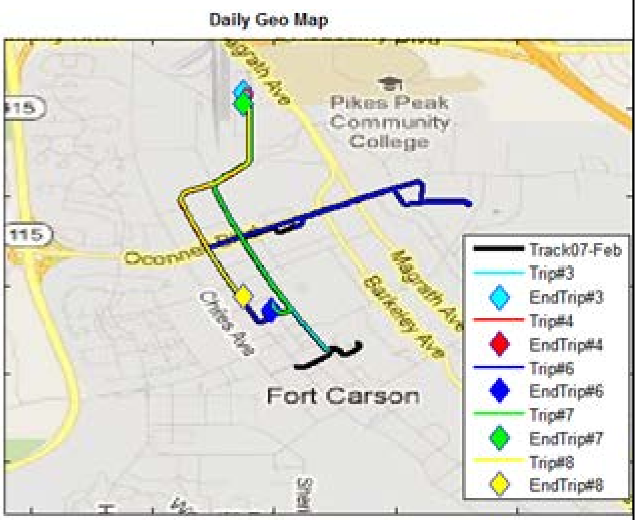


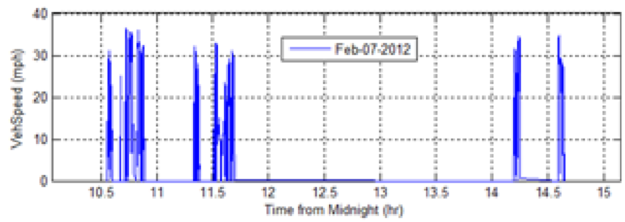


6-Feb-12		
TripN	Duration	Distance
(#)	(sec)	(mi)
1	214	1.0
2	43	0.2
3	268	1.5

Daily Geo Maps (Trips >1mi)

7 Feb 2012





7-Feb-12		
TripN (#)	**Duration (sec)**	**Distance (mi)**
1	150	0.7
2	37	0.1
3	265	1.6
4	263	1.5
5	209	0.7
6	695	2.4
7	215	1.3
8	206	1.2

Appendix F: Sources

1. Walkowicz, K. “Duty Cycle Analysis & Tools: Maximizing Vehicle Performance.” October 28, 2009. HTUF 2009 Conference – Atlanta, GA

2. United States Department of Defense. PLUG-IN ELECTRIC VEHICLES Request for Information. June 16, 2011.

3. O’Keefe, M. “Duty Cycle Characterization and Evaluation Towards Heavy Hybrid Vehicle Applications.” Society of Automotive Engineers Paper No. 2007-01-0302, 2007.

4. Department of Defense Annual Energy Management Report - Fiscal Year 2010.

5. Abuelsamid, Sam. “How do hybrids and electric vehicles blend regenerative and friction braking?” 18 February, 2010. Autobloggreen.